THE EFFICIENCY OF PUMPS AND EJECTORS

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BY

E. C. BOWDEN-SMITH, M.I.Mech.E.

LATE EGYPTIAN CIVIL SERVICE

AUTHOR OF

'OIL FIRING FOR KITCHEN RANGES AND STEAM BOILERS,'

'THE SUBSOIL OF CAIRO,' 'INVENTION, AN ELEMENTARY ANALYSIS,'

'THE GREATEST POSSIBLE POWER FOR THE LEAST POSSIBLE WEIGHT,' ETC.

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FOREWORD

RANKINE defined efficiency as the ratio of useful work to energy expended. No doubt he was particularly referring to the heat engine; but if we substitute £. s. d. for energy—that is, the cost of conversion and application—the definition is equally applicable to the subject under discussion. After all, the mechanical efficiency is simply the relative value of one power engine to that of another. The term is one of comparison, in whatever respect it is utilised. To regard with discriminating attention the means employed to perform a certain task is essential to progress, and the surest method of disposing of misconception and prejudice.

The object now in view is to throw some additional light on the most efficient method of raising crude sewage. What is well known will not be amplified, what is obscure will be analysed, and that which is open to question substantiated, with records and precise information as to how they were obtained.

At the same time, chapters have been given on the sinking of Ejector Tubbings, faults and remedies in the erection and working of Ejector Systems, and suggestions as to how the efficiency may be improved. There has been no attempt to cover the whole ground, but to enumerate and discuss those points which tend to the economical raising of crude sewage, which are not to be found in the engineers' handbooks on city drainage.

A mere statement of original data on which results

are based is neither convincing nor satisfactory, as the basis of calculation must be above contention. The efficiency of the motive power has been repeatedly determined, but the efficiency of the mechanical apparatus that does the work is often a matter of controversy. Especially is this the case in drawing comparisons between pumps and ejectors. The pump maker recommends his pump as the most efficient engine. The ejector maker recommends his ejector as the most efficient engine. And the purchaser, in nine cases out of ten, is left to decide on mechanical efficiencies obtained at a prearranged trial, and second-hand contradictory evidence applicable to those conditions of locality from which the information is derived.

E. C. B.-S.

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CONTENTS

CHAPTER I

EFFICIENCIES AND RECIPROCATING PUMPS

CHAPTER II

CENTRIFUGAL PUMPS AND EJECTORS

CHAPTER III

MECHANICAL EFFICIENCY OF PUMPS AND EJECTORS

CHAPTER IV

COMMERCIAL EFFICIENCY

CHAPTER V

STAFF: SUPERVISING

CHAPTER VI

SINKING AND ERECTION OF CAST-IRON TUBBINGS

CHAPTER VII

EJECTOR AND AIR-MAIN FAULTS AND REMEDIES

PAGE

CHAPTER VIII

THE SANITARY EFFICIENCY

CHAPTER IX

POWER HOUSE

CHAPTER X

IMPROVEMENTS

ILLUSTRATIONS

CHAPTER I

EFFICIENCIES AND RECIPROCATING PUMPS

Efficiency Defined.

In referring to the efficiency of the method employed in raising a liquid, the mechanical efficiency and the first cost are too often permitted to be the deciding factor on which a decision is made. In raising crude sewage, there is not one efficiency, but three efficiencies of equal importance that must be considered.

They may be defined as follows :

A. The Mechanical Efficiency.

B. The Commercial Efficiency.

C. The Sanitary Efficiency.

Mechanical Efficiency.

The mechanical efficiency is plainly a technical term that relates to the proportion of useful work done by the power employed to do it. Compared to 'B' and 'C' it can be accurately calculated by the engineer and manufacturer. Guaranteed on a trial, and, provided the apparatus retains that efficiency, it is possible to raise a certain volume of liquid each year for a certain expenditure in fuel.

Commercial Efficiency.

The commercial efficiency is the cost of raising the liquid. Not only the yearly expenditure on maintenance

in proportion to the volume raised, but the capital cost of the installation, the laying of sewers, purchase of land, compensation, and every expense that can be reasonably foreseen must also be considered. Inexpensive machinery may result in high maintenance. On the other hand, additional capital expenditure may be justified by economy in working.

Sanitary Efficiency.

The sanitary efficiency obviously embraces the whole undertaking, and cannot be confined to the machinery. It is synonymous with cleanliness and health. In fact, it is a stipulation that neither directly nor indirectly shall the effluent to be raised become a nuisance to the public. Expense on this head is an insurance policy against disease and offensive odours. If one type of pump or ejector will raise the sewage in a less offensive manner than another, it should be carefully considered, even if the initial expense is greater.

Raising Sewage: Various Methods.

Exclusive of exceptional situations, where a natural fall can be utilised as a motive power, such, for instance, as the hydraulic-lift system, the methods of raising sewage in common use are as follows:

1. The single-acting Ram Pump.
2. The double-acting Plunger Pump.
3. The Centrifugal Pump.
4. The Pneumatic Ejector.

They are representative of the class of machinery usually adopted; but it must not be assumed they are placed in order of merit, as that is a matter of opinion, dependent on the particular work they have to do.

Crude Sewage Defined.

Mechanically speaking, crude sewage consists of the effluent discharged by city sewers, containing every conceivable substance and variety of refuse that may cause obstruction or destruction to mechanical parts. Storm water and land drainage do not offer the same difficulties, and it is an error to assume that a pump which is efficient in one case will be equally efficient in the other.

Pumps: Analysis.

Superficially a fluid pump is a simple mechanical apparatus. Analytically it is one of the most enigmatical power problems that exists. And furthermore, it may be stated with confidence that there is nothing more difficult to lucidly explain and logically discuss than the complex and intricate behaviour of the forces set in motion. Many people, even engineers, are under the impression that a pump which will discharge water continuously and efficiently is equally suitable for raising a drainage effluent. No greater fallacy ever existed.

To pump water under the average city supply conditions the highest class of machinery is required; but to pump drainage an altogether superlative excellence of design and workmanship is necessary if any measure of success is to be attained. Many circumstances which cannot be foreseen have to be provided for, that are far beyond the calculations of the mathematician or the ingenuity of the most intelligent draughtsman.

The true sewage pump, it must be remembered, should be able to raise and discharge a liquid or viscous fluid containing every conceivable substance and variety of refuse, which may cause obstruction or destruction to mechanical parts.

It is not proposed to cover every point in connection with the subject under discussion, but merely to lay stress on some of the salient features and analyse the component sections that go to make up the complete machine.

At the same time it is as well to touch on some of those elementary laws which govern flow and pressure, and examine those conditions which are detrimental to efficiency. There must be a full appreciation of the relative value between the power, the machine, and the work it is doing.

The power is the force generated. The machine is the medium of transmission. The work to be done is that to which the power is applied. The object is to maintain an equilibrium between the power and the work, the one balanced against the other. The more accurately and scientifically this is accomplished, the less will be lost in the process of conversion. As far as we are concerned for the present, the source of all power is the heat engine in one form or another. Steam can be applied directly to the work—that is, can be brought in contact with the water to be raised—but from the nature and temperature of the two fluids the result is so wasteful that it is not a practical proposition for permanent use.

Water : Behaviour in Motion and under Pressure.

The text-books tell us what should and ought to happen when a moving column of water is suddenly checked or the inertia of a fluid has to be overcome ; but the alarming shocks and amazing pressures that are at times produced are far beyond what theory can at present account for.

The action of free water is more or less understood.

For instance, the pressure due to an impinging jet on a plain surface is just twice as great as pressure due to the head of water corresponding to the same velocity. But, supposing the jet takes place in the interior of a pump-chamber (when the gauge on the main indicates 100 lbs. to the square inch), and is met directly or obliquely, or in any direction we like to imagine, by similar jets, what local friction is set up ? and what is the loss due to their action ? Add to these conditions an intermittent and unknown quantity of air, which is, of course, highly compressible together with solid matter, and it will at once be realised that to analyse the action of the elements we have set in motion is a problem that cut-and-dried formulæ will struggle with in vain.

Science tells us that when a piston descends into a closed chamber containing a liquid, an equal pressure is exerted on each square inch of the interior of that chamber.

Precisely so.

And, provided there is a uniform resistance on each square inch of that interior surface, the liquid is free from frictional resistance of the water particles. But when we have a rectangular chamber into which the liquid is admitted and expelled through a series of suddenly opened and closed orifices, it is clear that violent streams and eddies are produced.

Tumultuous conditions exist, which are without doubt detrimental to the efficiency of the pump, but about which little or nothing is known. That there is a loss of energy due to this cause there can be no question, not only by 'fluid friction' between the fluid and the walls of the chamber, but by the frictional resistance of the particles of the water or 'loss by shock.' Again, actual variation in pressure of as much as 20 per cent.

in a constant speed pump clearly demonstrates that this loss by shock and fluid friction is progressive in proportion to the viscosity of the fluid, and percentage of solid contained, if a certain velocity is exceeded.

Opportunities to determine such problems are rare, as the necessary conditions cannot be reproduced in the test house or laboratory; and yet until some advance in this science of friction is made, one cannot define with any accuracy the cause of the variations in pressure and tremendous concussions that occur.

It is obvious, too, that a volume of water, the particles of which are in violent conflict with each other, cannot be impelled under pressure with the same power that it takes to impel a regular stream, as the kinetic energy of the liquid is entirely lost by the adverse currents set up, reacting on each other, and creating unknown resistance or negative action. With moderate pressure and low velocities, the negative forces are of little importance compared to the detrimental effects when velocities are high and pressure great.

Pumps: Reciprocating.

The double-acting plunger pump fitted with large rectangular clear-way valves in place of multiple valves of the disc and grid type is frequently installed for raising sewage. But it is often costly in upkeep and the chambers do not readily clear themselves of solids and vegetable matter. Neither does it embody that essential feature, extreme simplicity, which gives first place to the single-acting ram pump. The leading manufacturers recommend this type, and there is little doubt they are fully justified in doing so, when it is borne in mind that it is not the actual liquid that presents the difficulties, but the foreign matter contained that must

be provided for. There is no intention of dwelling on the 'power end' as that is a separate subject, and does not affect the 'fluid problem.'

The water rams may be operated by a reciprocating piston on the same rod, or by means of a rotary crank and connecting rod. Hence power pumps are usually termed direct acting, or rotary crank and flywheel pumps.

The advocates of the one type will vehemently disparage the advocates of the other, but when the action of the ram is carefully weighed and considered, it is obvious the rotary motion is superfluous; and in the direct-acting type, whether actuated by the interposition of a beam or not, we have the immense advantage of a pause at the end of each stroke, which allows the valves to close quietly, thus mitigating wear and tear. The alleged superiority in efficiency of the rotary type is by no means undisputed when it comes to the total expenditure on buildings, plant, and maintenance, especially since the introduction of the high duty compensating type. We have only to turn back to the days of the celebrated Cornish pumps, to see from their records that the duty they maintained is still unapproachable by the vast majority of the present day. They may indeed be described as the parents of water-raising power engines. The construction and action of the single or double-acting reciprocating pump may be described as follows.

The body of the pump consists of a closed chamber in which a ram or plunger reciprocates. That is, it descends and rises or travels backwards and forwards by means of a piston rod, or the ram itself passes through a water-tight stuffing-box. On to the walls of this chamber are cast or bolted two hollow covers, one form-

ing the suction chamber and the other the delivery chamber, the suction pipe and the delivery pipe terminating therein respectively. In the divisional walls are a number of orifices, which are closed by valves or lids which open in one direction only. Thus we have three chambers distinct from each other closed to the atmosphere, the suction chamber, the pump chamber or body, and the delivery chamber.

The action is as follows. Assuming the pump to be fully charged with water, the ram is withdrawn, a vacuum is formed, and the water forces open the suction valves. When the pump chamber is full, the suction valves close and the ram descends, forcing the water through the delivery valves into the rising main.

Plate I. shows the general arrangement of a small (64 H.P.) single-acting triple ram pump used for discharging crude sewage at a head of 290 feet. Fig. 1 shows a cross section and Fig. 2 a sectional elevation.

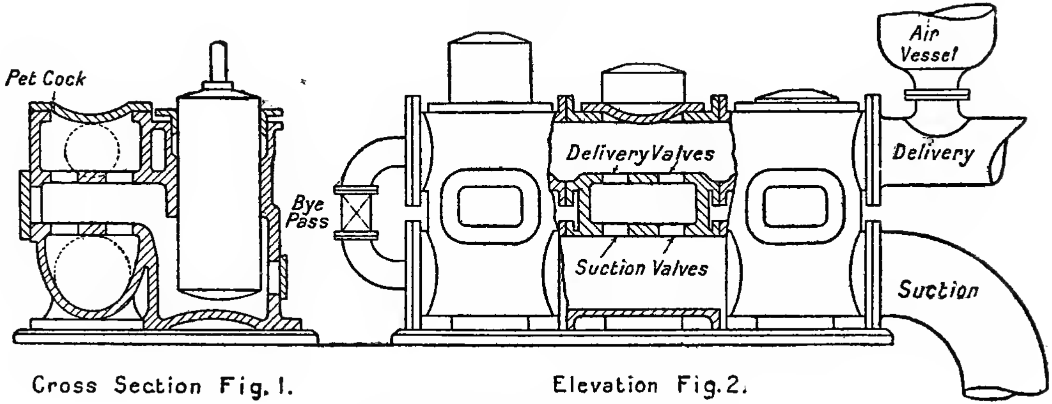
Each barrel is distinct from the other, but they draw from and discharge into chambers common to all three.

It will be observed the position of the barrels, convex covers, and internal surfaces gives us a compact casting of great strength, but is the cause of excessive friction and must produce cross currents altogether beyond defining.

We cannot change the direction of a fluid without dissipating its energy, *i.e.* by the abrupt deflection of a stream of water we lose velocity or action in direction of motion.

Now every action has an equal and opposite reaction, and therefore it is clear the less we change the direction of the fluid stream in the interior of the pump the more resistance is reduced.

PLATE I



Cross Section Fig. 1. Elevation Fig. 2.

SINGLE-ACTING RECIPROCATING PUMP

Pump Suction.

As the suction and all that appertains to it is the most vital section of the whole machine, it merits first place in discussion.

We have, as it were, to entice the liquid into the pump chamber. Once there, the motive power will not fail to send it forward on its journey. That the pump chamber should fill with liquid is of the utmost importance, as even a small percentage of air is responsible for violent concussion, the momentum and inertia of the water being aggravated by the compression and expansion of the air, besides reducing the discharge of the pump. It is literally impossible to exaggerate the importance of the suction arrangements. They are the foundation of the whole working system.

On the delivery side of the pump, we may stretch a point to suit structural convenience, but for the suction nothing will do which can be bettered. We cannot afford to disregard a single item of knowledge that we already possess. The remotest chance of air finding its way into the suction must be rigorously guarded against. The pipe should be as short as possible, and well immersed. Every joint is a joint too many, and every foot is a foot too much. Perfection and absolute perfection should be aimed at, even if it is not attained.

Suction Wells.

Some engineers attach importance to the contour of the sides and floor of the suction wells. There is little doubt this subject merits attention, especially when the sump is of restricted area and little depth.

Large volumes of water in motion inevitably create eddies and disturbances when brought into contact with

angles and projections in the masonry. All these irregularities should be avoided if a smooth and even flow is desired free from turbulent and conflicting currents. Separate wells for each suction are a great convenience in many ways, and the possibility of one intake interfering with another is entirely obviated.

Air in Pumps.

It must not be supposed that because there is no actual leak, or the water actually below the rim of the intake, that no air can enter the pump.

A drainage effluent in particular is notoriously highly aerated, and frequently an amount of gas is generated which is positively astonishing, especially in semi-tropical climates. Therefore it is clear the liquid is often charged with myriads of minute bubbles or imprisoned globules of vapour. These globules have one common ambition—that is, to rise and free themselves from the liquid. The result is they unite with each other as they are drawn into the pump, and are caught or retarded by any irregularity in the casting, in which they can lodge, for instance, in the angles and beneath the convex covers.

The smallest bubble cannot be compressed out of existence, and although in course of time they will 'work out' unless there is an absolute pocket, it does not detract from the harmful effect they have already caused. Hence the extreme care with which the interior lines of a pump should be designed.

There is little doubt that air is the cause of three-quarters of the concussion and reduced discharges, because air, being highly compressible and water incompressible (for practical purposes), the ram descends, compresses the air instead of discharging the water,

and the expansion of the air as the ram rises retards the filling of the pump chamber.

This process is beautifully illustrated, if by accident or purposely a hole is knocked in the bottom of the ram and the pump drained; on restarting, it will then be found that almost the entire stroke of the ram is taken up in the compression and expansion of the same volume of air, without the admission or discharge of water through the pump valves. A striking illustration of 'excessive air' can also be observed on starting a pump drawing from a drainage sump that has remained quiescent for some hours so that gases are being freely liberated on the surface in the form of bubbles. For the first half-hour irregular working accompanied by concussion is experienced at every revolution; but when comparatively clear water is drawn, no matter whether it is at a much lower level, normal conditions prevail.

Matter in Pumps.

Of almost equal importance to excessive air is the variable percentage of matter the liquid contains, which, in exceptional cases, produces remarkable results.

When a pump, accustomed to draw and discharge an effluent highly charged with refuse and viscous matter to such an extent that the interior of the chambers and rising main become thickly coated with a glutinous substance, shows a pressure of 105 lbs. to the square inch on the gauge, and is called upon to discharge clear water for some days, the gauge pressure rises to 125 lbs. to the square inch, with corresponding increase in the consumption of motive power. The interior of the pump and suction will then be found perfectly clean, but the rising main is still in a foul condition. A circular pipe such as a rising main would

naturally be more difficult to clear than a pump chamber, owing to the regularity of the stream and absence of turbulent conditions, and the additional velocity, which is the cause of the extra pressure, is probably greater at the centre of the stream than at the sides.

If the viscosity of the fluid is very great, cavitation and separation will take place with the usual concussion as the chambers fail to fill, and to remedy this fault it would be necessary to reduce the speed of the pump or increase the exterior pressure.

Strainer for Suction Pipe.

Suspended matter and solids are naturally drawn towards the intake, and therefore we must make provision to ensure their easy passage through the pump.

A rose or strainer attached to the pipe rapidly becomes choked, thus checking the flow into the pump chamber, which is the worst of all evils, and experiment conclusively proves that a mesh sufficiently fine to stop canes and sticks, etc., is sufficiently fine to prevent the passage of vegetable matter. So the strainer must be abolished, and in its place a grating of wide area should be provided, and set up as far from the suction pipe as possible, the material and mesh, which are subjects of great importance, being decided by local conditions.

And furthermore, liberal arrangements must be made, either mechanically or by hand, to prevent the mesh or bars from becoming choked, thus banking up the liquid, and allowing the water to reach a dangerously low level in the suction well.

Foot Valves.

With water pumps a foot valve is usually attached to the end of the suction pipe—that is, immediately

above the strainer. It consists of a valve box containing two semicircular flap valves with a common hinge, and is for the purpose of retaining the water in the suction pipe, so that the pump can be easily started.

But this valve is an additional working part, and in sewage pumps is easily made inoperative by the finest cane, and is often a source of endless trouble. Without question it ought to be omitted if circumstances permit of fixing a steam ejector for charging, otherwise special arrangements must be made for rapidly draining the sump by independent means, so that the valve can be cleared by hand.

Air Vessels.

We now come to an item of endless controversy, namely, the air vessel. It must, however, be distinctly understood that these remarks on this subject exclusively refer to the type of pump we are dealing with and the conditions under which it works. What is a valuable accessory in one case is a superfluous nuisance in another.

There is a popular notion, that an air vessel absorbs shocks, but this depends entirely on the nature and origin of that shock. If the shock takes place in the body of the pump itself, as it usually does, and the air vessel is placed on the delivery main, as it often is, it is incontestable, from the briefest experience, that whatever percentage of the shock the air vessel absorbs is a negligible quantity.

In the old-fashioned slow running bucket and plunger pumps, an air vessel of ample capacity was a necessity to ensure a more or less uniform delivery. Its functions were, in fact, to compensate for the inequality of the discharge by means of the compression and expan-

sion of the air it contained at each stroke of the plunger, but if the flow is constant it is obvious that its principal function ceases to exist.

It is an open question what effect it has on a constant flow, and the only use it can have is to rid the pump, or rather the main, of a certain quantity of air, that is, performing the function of an air trap or pocket. On the other hand, with constant flow, great pressure, and high velocity, it often appears to cause vibration as the highly compressed air simply acts as a vibrating spring, magnifying shocks and becoming a real source of danger if a casting fails, as the expansion of the air causes the fractured pieces to fly with great force.

Pump Valves.

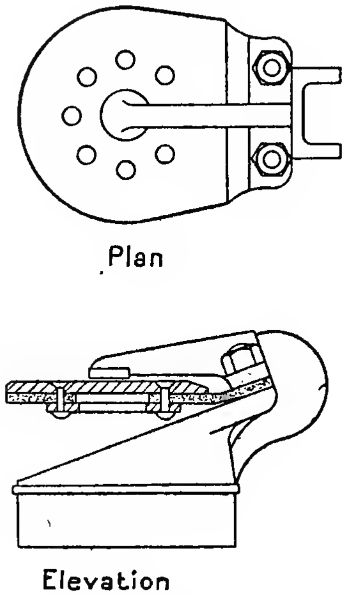
For passing crude sewage, the clear-way flap valve with leather or pin hinge or the multiple clear-way type are the only ones that merit discussion. There must be neither grid nor central guide to impede the passage of solid matter.

Plate II. shows a leather-hinged valve. In large pumps, five or six large rectangular valves of this type will be fixed to a valve plate, the valve seats being part of the plate. It is probable that the leather-hinged valve has been in use since the earliest days of power pumps, and it has indeed a somewhat primitive appearance. Nevertheless it may be regarded as a standard design for sewage at the present day, and at moderate pressure, with a weak effluent, performs its functions in a more or less satisfactory manner. But when it is used for high pressures and strong sewage containing quantities of grit and refuse, its failings completely outweigh its advantages, and it is hard to understand how engineers have rested content with its

imperfections. At low pressure it is true they are only apparent to those who carefully consider the action of the liquid and behaviour of the valve; but when the pressure exceeds a certain value, the faults are rapidly superseded by failures and its supposed merits are converted into glaring defects.

As this valve is of historical interest, let us analyse

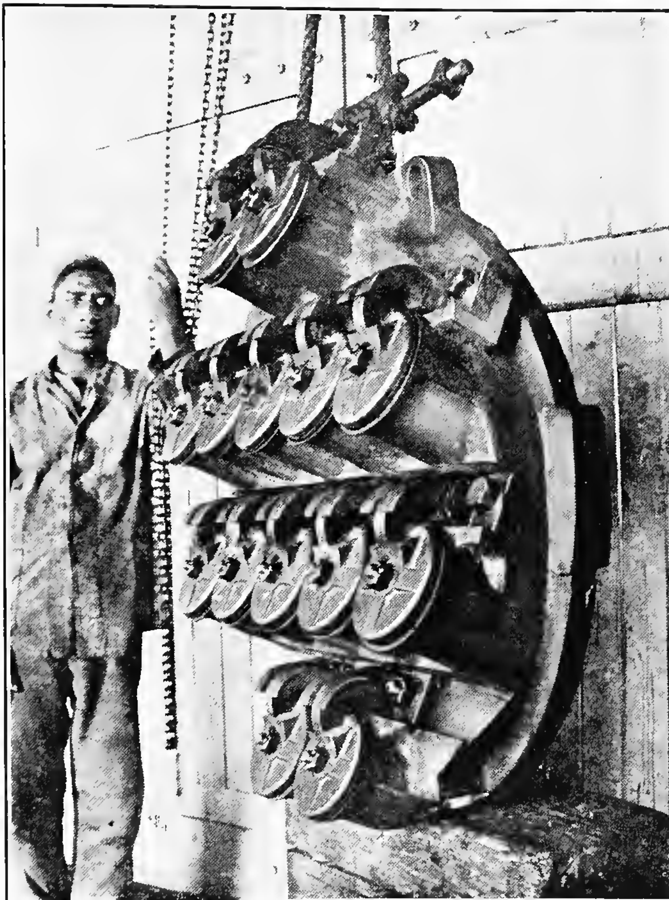
PLATE II



LEATHER-HINGED PUMP VALVE

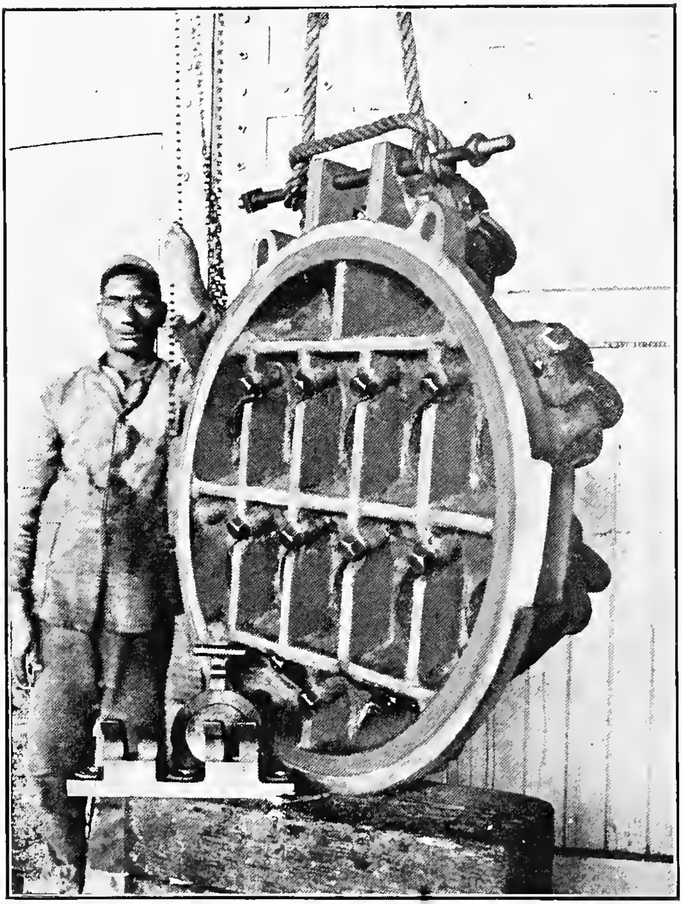
its construction and action. Briefly, it consists of a wrought-iron plate, to which is riveted a clack of leather by means of a wrought-iron washer, on the underside, sufficient leather being allowed to project beyond the iron plate to form a hinge. This tab or hinge is pierced by two holes to correspond to the studs screwed into the lug on the valve seat. The foot of the arm or stop,

PLATE III



Multiple Clear-way Valve Plate (front view)

PLATE IV



Multiple Clear-way Valve Plate (back view)

which controls the lift of the valve, forms the necessary washer, the whole being secured in place by two nuts. It will be observed that the valve is without guide, of extremely light construction, and the method of attaching the leather to the valve results in the forming of a cavity on the underside. Now a light valve without spring is frequently hammered on to its seat with a crank pump, and the excessive wear with irregular motion leads to rapid destruction of the valve, and the seat itself will be battered by the iron plate. Saturated leather is a soft and pliant material, and, as the valve rises and falls under pressure, it is wrenched and torn by the fiercely conflicting currents of water.

In clear-water pumps multiple valves are the standard practice. There is less slip, less wear and tear, and a higher piston speed is possible, which all means increased efficiency.

Multiple Clear-way Valves.

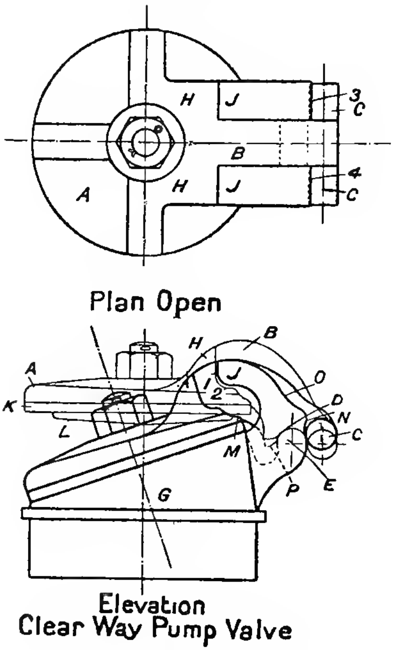
Plate III. shows the front view of a 200 horse-power multiple clear-way valve plate. Plate IV. is the back of the plate, showing its massive construction. There are six of these to each pump.

These valves have a clear way for the passage of solids and a leather face, combined with the independent freedom of the disc valve, but without the disadvantage of a hinge. They are so constructed that they can be removed and replaced on their seats with the hand through the inspection cover of the pump, without the aid of spanner, pliers, hammer, or tools of any description. In practice it has been found that these valves use six and a half times less leather (owing to reduced wear) than the standard leather-hinged type.

They can be adapted to almost any type of pump.

Plate V. shows a single valve and its seat, of the horizontal type. It will be observed the design of the valve ensures a uniform motion, which is the great merit of the disc type. The valve consists of a circular metal disc *A*, on which is cast a heavy arm *B*, terminating in two projecting pins *C* at right angles to the arm *B*. In the underside of the arm *B* is a recess *D*, which rests

PLATE V



CLEAR-WAY PUMP VALVE

on a corresponding ridge *E* cast on the back of the valve seat *G*. On the upper surface of the valve *A* are cast two stops *H*, which are disposed in such a manner as to engage with the extremities of the two lugs *J* cast on the valve seat *G* when the valve is fully open.

In this example a leather or composition face *K* is fitted to the underside of the valve, by means of the combined stud and washer *L*. By this means it is clear the face *K* can be easily replaced.

It is obvious that as the valve is lifted by the fluid the space between the lugs *J* forms the guide in which the arm *B* works, thus obviating all chance of side motion. The recess *D* resting on the ridge *E* prevents the valve from having any tendency to slip either forward or backward when closed. Furthermore, by this means we obtain a maximum aperture at one extremity of the valve with a minimum turning motion at the other. Also, it must be noted, any wear taking place at the point of contact *D* does not affect the water-tightness of the valve face upon the seat as the valve is entirely free to the pressure exerted by the fluid. When the valve is in operation, arm *B* slides backward as it rises and the pins *C* are of a necessity depressed.

At its maximum opening the valve is absolutely rigid with the seat by reason of the stops *H* engaging with the lugs *J* at the points 1 and 2 and the pins *C* at 3 and 4—that is, six points in all.

To remove the valve from its seat the front must be kept depressed while the pins *C* are raised; at the same time the whole disc is pushed backward till the point *M* comes in contact with the underside of the lug *J*, when it will be found that the pins *C* are clear of the projection *N*.

By continuing to raise the pins *C* and keeping the front of the valve depressed, the whole disc can now be drawn forward, the pins *C* sliding over the back of the lugs *J* by reason of the curve *O*, and thus the arm *B* is easily withdrawn from the guide.

To replace the valve the reverse process is required,

and the projection P prevents the valve from coming to rest in a faulty position.

Although this description may appear complex, it is not difficult to see that in practice the operation of removing the valve cannot exceed a few seconds, even when situated in a totally inaccessible place, to the ordinary type.

Plate VI. shows the front and side view of a rectangular form of multiple clear-way valve for a large sewage-pump valve plate.

The plate is a large one and originally contained 33 valves in 11 rows, with three valves to each row.

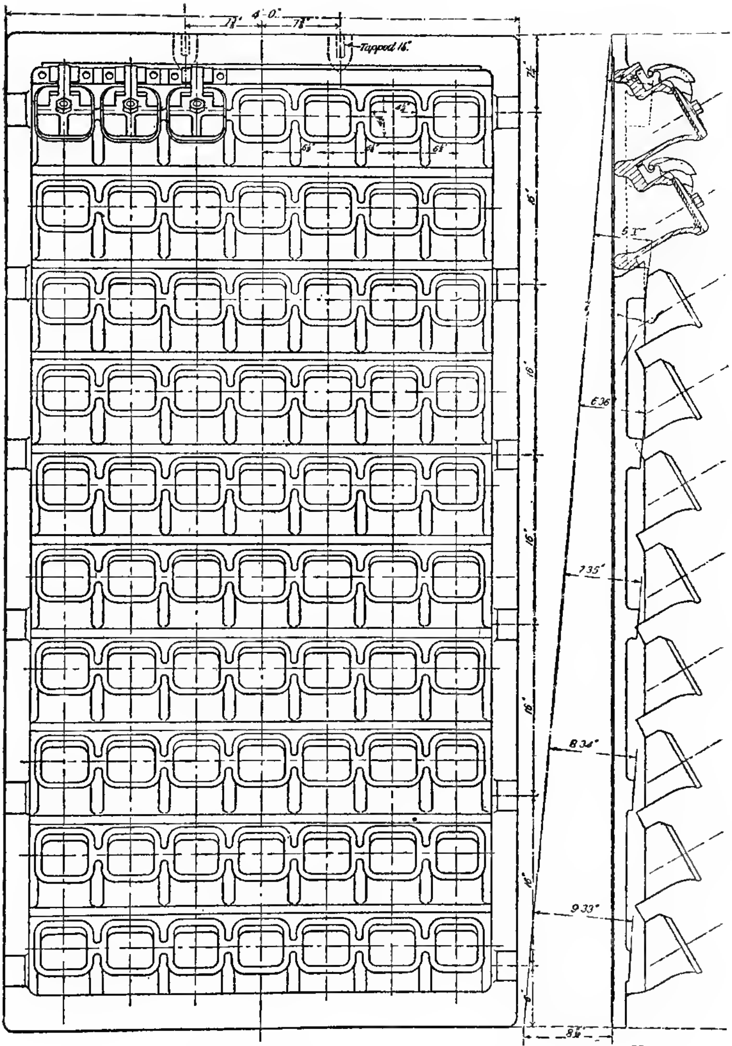
It will be observed the plate now contains 70 valves in 10 rows, with seven valves to each row, with a guide to each valve and no hinge pin to wear.

Plate VII. shows another design, consisting of a nest of four valves, which have been substituted for a single 9-in. double-flap valve, set horizontally in the pump chamber of a direct-acting plunger pump.

In pumps of the largest dimensions, which contain many scores of valves, the enormous saving in time and labour alone resulting from the adoption of a design which can be removed and replaced with such ridiculous ease, instead of by the old method of extracting pins and manipulating obstinate nuts eroded by the action of the effluent, is too obvious to need dilation.

From a superficial inspection of the drawing it would appear, at first sight, that the valve would not retain its position, but the pressure of the water on the underside is so exerted that the front of the valve cannot avoid being lifted, in which case the opposite extremity is bound to be depressed, neither can the liquid impart the necessary consecutive movements to free the valve from its true working position. Hence it may be described

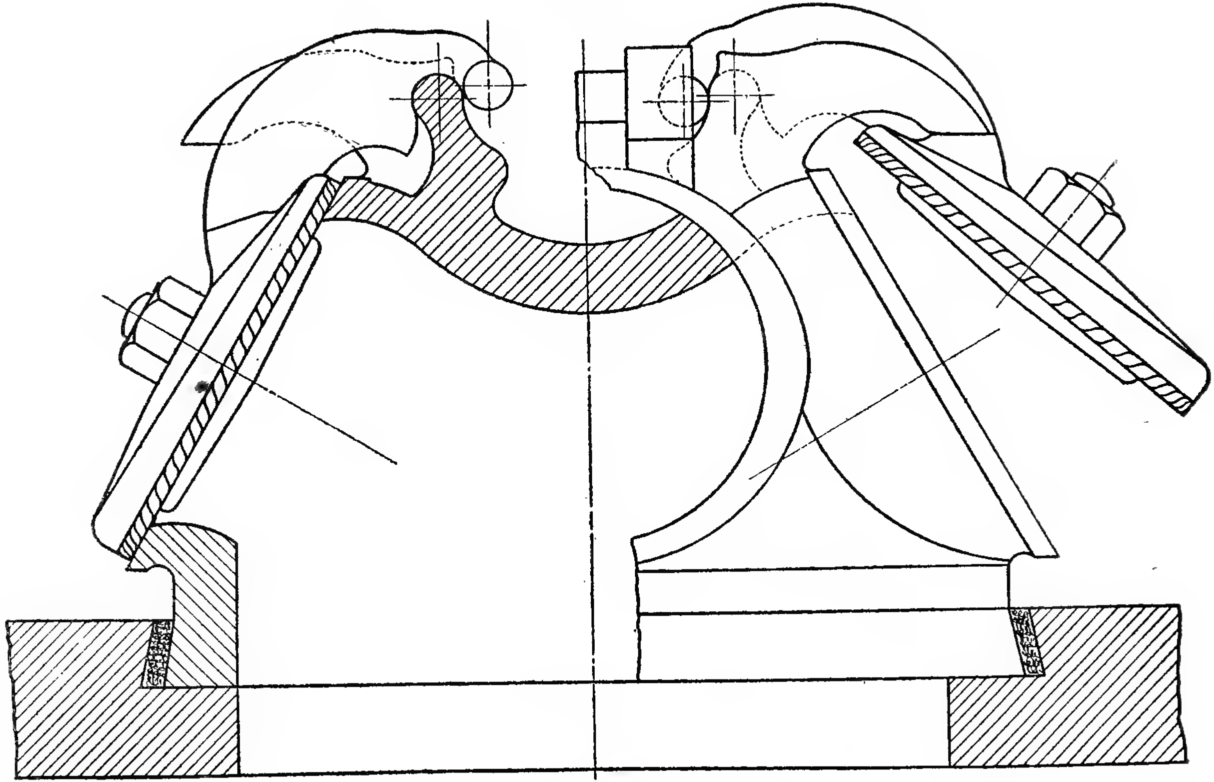
PLATE VI



— Front View —   — Side View —

MULTIPLE CLEAR-WAY VALVE PLATE

PLATE VII



Nest of Clear-way Pump Valves

as an independent clear-way multiple valve, as there is neither nut, screw, nor pin that attaches the disc to the seat. The necessity for large inspecting covers for the purpose of inserting and manipulating tools may be abolished, as the valve can be placed in position and extracted, even when covered with liquid in a confined position. This valve, it will be noted, is of heavy construction, and the leather face is kept in position by a single mushroom-headed stud, which not only deflects the liquid with a minimum of friction but allows the leather to be replaced in a few minutes.

If we bear in mind that there is 100 lbs. to the square inch above the valve as well as below it, and if the area is sufficient to easily pass the required volume, there is no reason to assume that excessive leverage exists. After two years' work at 290 ft. head these valves showed no scoring or defects.

This valve under heavy pressure with 'a gritty' liquid is undoubtedly superior in water-tightness and length of life to the leather-hinge type, and the merits of the multiple valve over the old-fashioned rectangular sewage valve in durability and efficiency are too well known to be repeated.

CHAPTER II

CENTRIFUGAL PUMPS AND EJECTORS

Centrifugal Pumps.

The centrifugal pump finds much favour in certain localities where the liquid is in great volume with a low head, short delivery, and uniform working conditions.

It has the immense advantage of being without valves; but the drawbacks are of such a description that it is not expedient to install them unless the precise nature of the work it will have to do can be stated.

It is a fixed mathematical calculation which neither permits of modification in speed, additional head, or mechanical wear without impaired efficiency. When very large volumes have to be dealt with at low heads, the mechanical wear is insignificant; but in small pumps of this class a high efficiency rapidly disappears. Again, if it is called upon to deal with a viscous fluid and the friction is increased, it will practically cease to discharge. The centrifugal pump is, however, without doubt the most popular method of raising sewage, and is particularly well adapted to a motor drive, or a belt drive from small internal-combustion engines.

It is cheap to install and gives a good mechanical efficiency on trial.

In these pumps a constant velocity is imparted to the liquid in a suitably designed casing, by means of an impeller, consisting of a hollow disc which is divided into passages or ducts by means of radial vanes or blades disposed in such a manner that the water enters the

centre of the disc, and is expelled from the perimeter when the disc or impeller is revolved at a high speed. This disc must rotate truly in its casing, and a machined surface is provided on the exterior of the impeller to coincide with a similar machined surface on the inside of the casing to prevent the expelled liquid returning to the suction pipe. That is to prevent 'slip.' It will readily be seen that if these points of contact or fine clearance become worn by sand and grit, excessive 'slip' will take place.

The action set up is uniform, the flow constant, but unless a fine screen is provided, small or high lift pumps of this description are liable to frequent stoppage from rubbish and solid substances becoming firmly wedged in the impeller ducts and fibrous matter fouling the internal clearances.

When such pumps are coupled direct to the power engine they form compact units, require light foundations, and are economical in engine-room space. On the other hand, many engineers prefer to erect them below the level of the water in the suction well, in which case deep excavations and heavy masonry chambers are required.

Centrifugal Pumps' Vertical Shaft.

In such cases the motors are arranged on the engine-house floor and connected to the pumps by vertical shafts.

The pumps, of course, are turned over and the impellers revolve in a horizontal plane. To take the weight of the shaft a thrust block is provided above the pump, and forced-water lubrication is required. Such installations are extremely neat in appearance, and for clear water are to be preferred in many ways.

For sewage it is doubtful if they are more satisfactory than the usual type, as it is necessary to have a pump that can be easily opened, and the vertical shaft has to be completely dismantled before this can be done. Inspection covers are provided in the pump casing; but it will be found impossible to clear the impeller ducts of pieces of wood and like articles through such small hand openings. For some reason fibrous matter collects in large balls round the nut which holds the impeller in position, and the grit in the effluent cuts deeply into the shaft under the rotating action. It must also be remembered they require sumps to draw from, and screening chambers and the necessary mechanical appliances connected therewith.

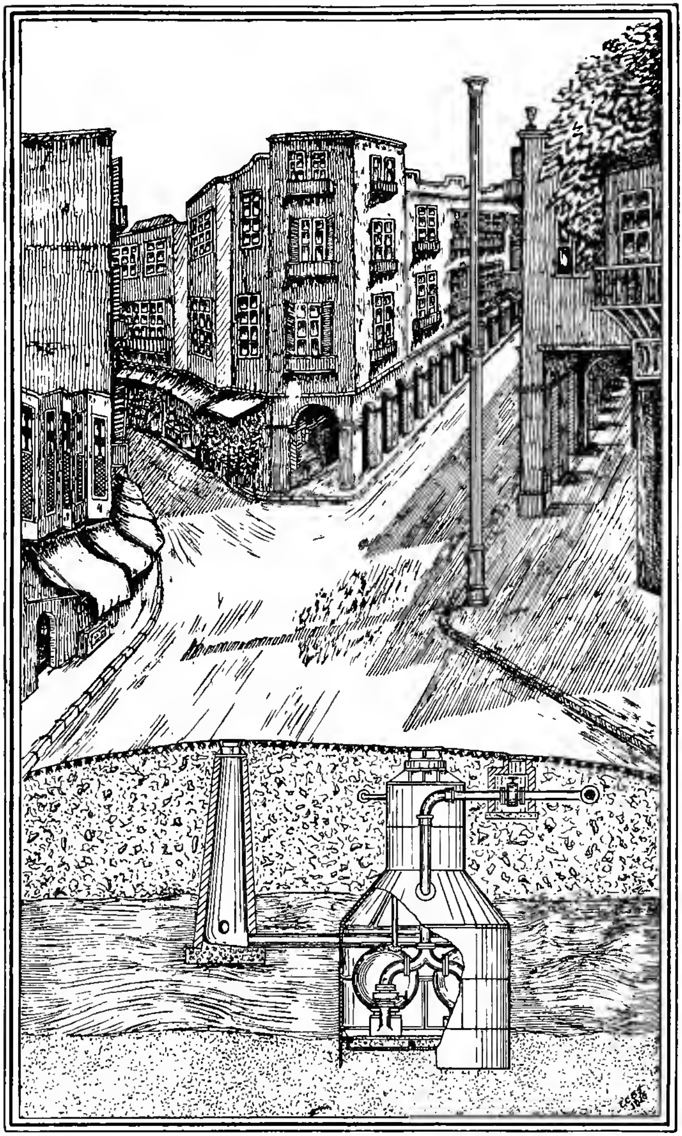
PNEUMATIC EJECTORS IN TUBBINGS.

Comparatively speaking, the pneumatic ejector is an obscure apparatus compared to a pump.

Plate VIII. shows a typical example of a pair of ejectors in a cast-iron tubbing sunk in water-logged soil consisting of rubbish, clay, and sand.

These tubbings are sunk with compressed air to a predetermined depth below the proposed invert level of the sewer manhole. In this example the depth sunk from the surface to the cutting edge is about 25 feet. In some cases the floor of the tubbing, which is composed of box-section, cast-iron plates, filled with concrete, is subjected to an external pressure of 100 tons. The inlet manhole seen to the left of the tubbing is 17 feet deep, from the invert of which the horizontal cast-iron inlet pipe passes through the tubbing wall to the ejectors. The delivery pipe passes out through the cone to the sealed sewage main, which discharges into the main

PLATE VIII



EJECTORS IN CAST-IRON TUBBING
(Sharia, Clot Bey, Cairo)

collecting sewer, possibly two miles distant, or direct to the disposal works by a main sealed sewer.

The air main enters the chamber through the uppermost ring shown to the left, and the exhaust passes out at the same level to the silencing chamber, consisting of a length of 24-inch cast-iron pipe (not shown), and thence to the atmosphere by means of the vertical steel column standing on the foot walk. The entrance to the tubbing is effected by a hinged cover at street level.

Subsidiary Ejectors.

Where ejector stations are situated in such localities that they would require a greater pressure to discharge the sewage than the maximum maintained at the power house, the sealed sewage rising mains empty into gravitation sewers, and the sewage is re-ejected a second time.

Such ejectors are subsidiary ejectors, of which there may be any number of stations.

Description of Ejectors.

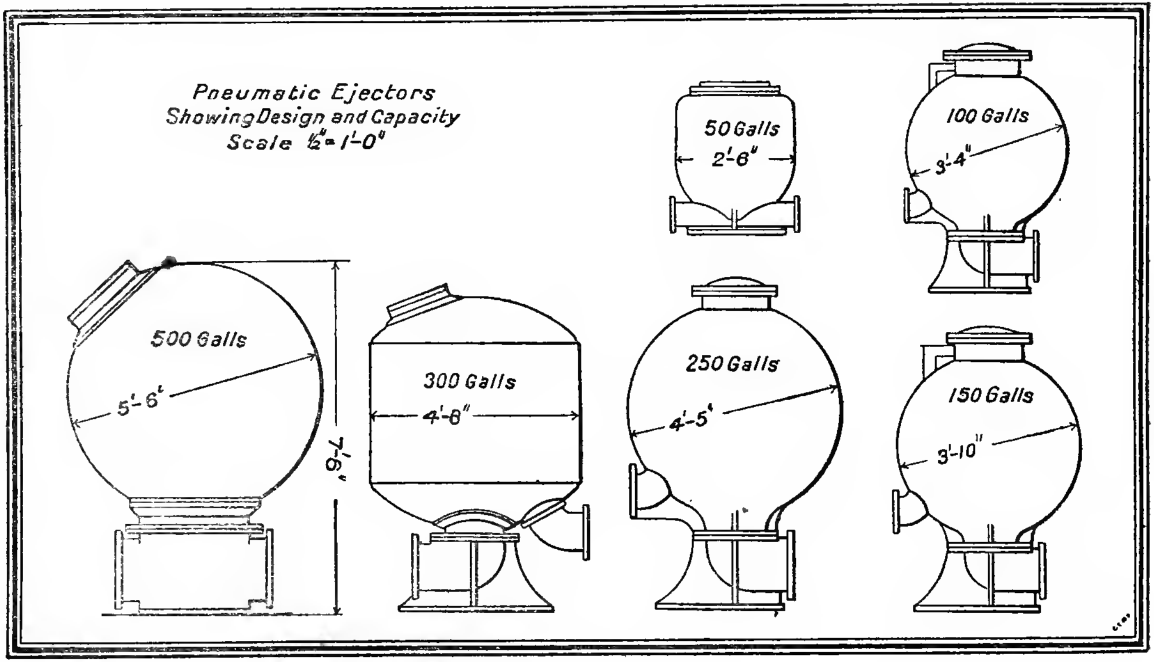
Briefly, the ejectors consist of spherical vessels of cast iron or steel from 50 to 500 gallons (or larger) in capacity (Plate IX.), into which the sewage flows by gravitation.

When full, the compressed air is automatically admitted and shut off as the contents are discharged.

They are arranged in pairs, as shown on Plate X., and work alternately or differentially, according to the volume of the sewage to be dealt with; but either of the two can be entirely shut off without interference to the other's working.

In this diagram (Plate X.) the ejector marked *NS* is full, the alternating valve *A* and the automatic valve *B* are open, and the air about to discharge the contents,

PLATE IX



Pneumatic Ejectors

while ejector *OS* is filling. The automatic valve *C* shows the air port closed and the exhaust open. These three valves, *A*, *B*, *C*, are controlled by the slide valves in the air chests marked *D*, *E*, under full pressure from the main. These slide valves are, in turn, actuated by the weighted lever attached to the rod passing through the crown of the ejector, to which a 'bell' or float *F* is attached and a weight *G* is suspended.

It is clear, as the liquid rises and falls, the slide valve must take up one of two positions, thus alternately releasing the air from either end of the piston valve cylinders. It will be observed the rise of the float *F* does not check the flow of the liquid into the ejector, but the admission of the air through the valves *A*, *B* or *A*, *C* pressing on the sewage.

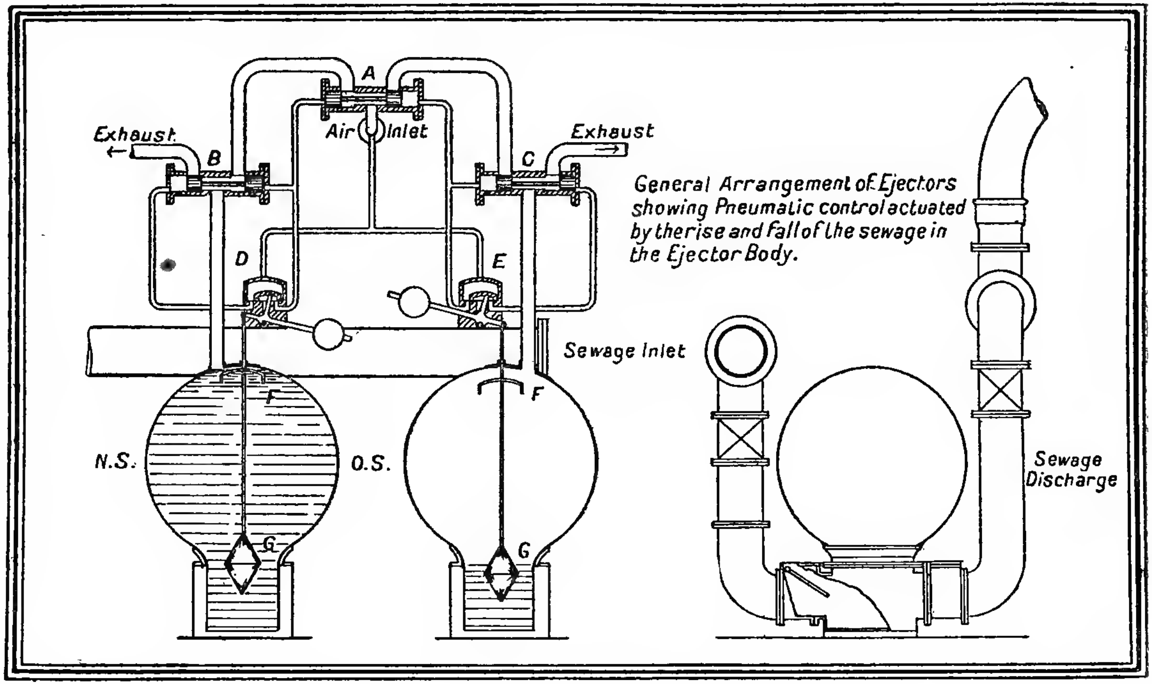
The valve *A*, being able to take up one of two positions only, the ejectors cannot discharge together, but they can fill together, and the one or the other of the two ejectors must wait upon its fellow to empty before the valve *A* is thrown over, though the valves *B* and *C* may have both air ports open together. Thus the ejectors may discharge, alternately or differentially, according to the volume of sewage to be dealt with.

Action of Ejectors on Sewage.

As a rule ejectors are designed to fill and discharge in one minute ; but in many cases this rate can be greatly exceeded, according to the head of water in the rising main and the air pressure available.

It will be observed, from the design of this apparatus, the compressed air exerts the necessary pressure directly on the surface of the liquid, till it has been discharged through an outlet in the base of the ejector. By this means all heavy matter is first expelled, having the

PLATE X



EJECTOR DIAGRAM

full volume of water behind it to carry it through the valves and rising main. This is precisely what a pump is unable to effect. Again, the ejector is ready to take the merest dribble or the maximum flow at a moment's notice.

The arrangement of the inlet and discharge pipes and valves can be clearly seen in Plate X. The action of the inlet or 'suction' and delivery valves is steady. There are no machined parts or internal bearings in contact with the liquid. There is no concussion or loss by shock from air or gas, as the ejector fills by gravitation against the atmosphere and discharges with a steady pressure. The direction of motion is constant: no cavitation or separation can take place.

There is neither centrifugal nor reciprocating action to cause loss of velocity by deflection. The compressed air is the impeller or piston. Comparatively speaking, there is nothing to repair, and there is nothing to wear out. It appears to be the most suitable mechanical apparatus devised for raising crude sewage, viz. a 'liquid or viscous fluid, containing every conceivable substance and variety of refuse, which may cause obstruction or destruction to mechanical parts.'

The limitations of the ejector are entirely due to the difficulty of obtaining a good mechanical efficiency when using compressed air as a motive fluid at high pressure without expansive working. The greater the pressure the greater the volume of air required to raise a given quantity of water, and the lower the mechanical efficiency; therefore, the higher the fuel cost.

Localities Classified.

Before proceeding to describe further details of the various systems employed for raising sewage and the

efficiencies they give, it is well to roughly classify the localities for which they are suitable, as it is obviously unjust to compare one method or machine with another if it is selected to perform certain work it was never intended to do.

On the other hand, whether a pump or ejector is installed they are both constructed of the same materials and subject to the same chemical action; therefore the installations selected for comparison should be discharging the same effluent, assuming, of course, the apparatus has been made and supplied for the work it is set to do.

It is exceptional to find representative types of all three of the methods enumerated above in a single sewage scheme, and herein lies much of the value of the observations and diagrams hereafter recorded and classified.

The conditions of locality may be roughly divided as follows:

No. 1. Situation where the natural fall of the ground enables the whole volume of sewage to flow by gravitation to a selected site near the city, from which site it is pumped with a maximum 'head' of 40 feet to the disposal works.

No. 2. Situation as above where the 'head' does not exceed 90 feet.

No. 3. Situation as above where the head exceeds 90 feet.

No. 4. Situation where there is no natural fall, possibly a water-logged soil and prohibitive reasons for laying deep sewers.

MACHINERY: SUITABLE CONDITIONS.

Situation No. 1. If large volumes of diluted sewage have to be raised with a short length of delivery main, the centrifugal pump may prove to be the most

economical, from the commercial point of view. But the depreciation in small units dealing with a gritty effluent, such as road washings, etc., besides domestic sewage, is so rapid that the pneumatic ejector, though more costly in the first place, will be found more economical over a number of years. The absence of sump and screening chamber also enables the ejector station to be situated in the centre of the town if necessary, without offence or inconvenience. In many cases the effluent does not have to be lifted more than 20 feet, or when discharging into the sea 5 feet or 6 feet. In such cases the difference in first cost may amount to a large figure.

Situation No. 2. Under such conditions there is almost certain to be a considerable length of rising main. With short mains centrifugal pumps might be installed, each pump having its own main; but the double-acting plunger pump would probably be the most efficient in such a situation.

Several units can pump into the same main, and such an installation can deal with a great variation in flow under exacting conditions. Within recent years, however, makers have placed ejector installations on the market for which they claim a high efficiency at 92 feet head, and when the effluent to be dealt with is strong this should be taken into consideration in competition with the plunger pump, as it will be shown in a later chapter, that the commercial efficiency of the pump is not so much greater than that of the ejector.

Situation No. 3. For a head of water above 90 feet the single-acting ram pump is usually selected without hesitation. The outside packed rams enable any wear to be taken up and a water-tight joint maintained. In mechanical efficiency it is unsurpassed, and its com-

mercial efficiency is largely a matter of care and attention. Like all other pumps, though, it requires a sump and screening chamber, and must be situated well outside the precincts of the city.

Situation No. 4. As a rule such conditions entail a somewhat higher capital cost for machinery, but a reduced cost in laying sewers. It is in such situations that the pneumatic ejector is invaluable. The area to be drained is divided up into sections according to local requirements, and at the lowest point of each area a masonry chamber is built, or a cast-iron tubbing is sunk in which to place the ejectors.

These chambers are connected by compressed-air mains to the air-compressing power house, which may be situated on any convenient site, as it is no more offensive than a tramway power house or an electric generating station. The ejector stations may be situated directly beneath the streets, as shown in Plate VIII., as there is no offensive sump or screening chamber.

When a large number of ejector stations are required there is usually a main artery into which the sealed sewage pressure mains from the ejectors discharge.

In cities that cover extensive areas, it is usually found advisable to provide subsidiary ejector stations, that is, one station discharging into another, in order to equalise the working pressure that must be maintained at the power house. In practice, 55 feet to 65 feet head is the maximum for economical working, but 45 feet is to be preferred, the frictional head of the cast-iron main accounting for a large percentage of the pressure. But the outstanding merit of this system is the absence of sumps or any accumulation of sewage. The effluent is discharged as soon as it arrives from the sewers, and no decomposition can take place.

Sectional Systems: Alternatives.

From time to time various methods have been suggested and demonstrated, with a view to retaining the advantage of the ejector, but eliminating one of the principal drawbacks, which is leakage from the air mains. That is to say, it is not the ejector with which fault is found, but the difficulty of efficiently transmitting the secondary power to operate the machine. It must not be overlooked, though, that the secondary power is directly applied to the work and is not converted into mechanical motion: thus the mechanical friction is eliminated.

Hydraulic System.

In order to avoid air-main losses some engineers favour the hydraulic system. Apparatus to raise the sewage is operated by water at high pressure, supplied from a central station, and distributed by means of cast-iron mains to the sewage pumping stations. It has been in use many years but has not been widely adopted, though exceptional local conditions may demonstrate it as more economical than the pneumatic system.

To substitute a high-pressure water main for a low-pressure air main may result in economy in the transmission of power; but it is a question whether it is economically sound to install high-pressure machinery and its accessories greatly in excess of what is required in the class of work we are dealing with. Again, unless a water supply of remarkable purity is available, there will nearly always be some fouling of working parts, or deposit, which with compressed air is entirely absent.

Centrifugal Pumps: Multiple System.

Within recent years many attempts have been made to employ small centrifugal pumps in place of ejectors, but they require considerable attention and are uncertain to depend on for automatic action. A central power station is required for generating the necessary current to drive the motors which actuate the pumps, and a system of distributing cables, in place of air or water mains, for transmitting the power.

The pumps are placed below the level of the collecting manhole, or enclosed container, and automatic arrangements for starting and stopping are employed. It is claimed for such pumps that no screening of the sewage is required, but no pump can retain its efficiency for any length of time when called upon to deal with road metal, bricks, tins, broken metal, etc.; on the other hand, the ejector suffers no loss of efficiency from passing such articles.

The principal merit of the electric transmission is that there is no loss of efficiency by leakage, as there is in the air mains. On the other hand, there is the friction of the motor and pump to be taken into consideration. In first cost little economy, if any, would be realised, as cables, switches, and their accessories are constructed of expensive materials.

Again, there are some advocates of a sectional multiple centrifugal pump system, operated from a central generating station, as just described, in which the object is to dispense with long lengths of rising main. By such means, it is claimed, frictional head is practically eliminated, and the whole power employed is utilised to raise the sewage to the required level.

To effect this, three or four collecting stations are

provided in place of one, each station being provided with motor pumps in duplicate, placed in a chamber alongside the sump from which they draw.

The pumps raise the effluent to a high-level gravitation sewer in close proximity to the station, from which it flows to the next station to be repumped, till it is discharged at the outfall. Screens are dispensed with in the sumps, but provision has to be made for removing heavy articles.

The pumps themselves are of special construction and cut up or disintegrate fibrous vegetable matter, cotton waste, discarded cloths, and materials of a similar nature, therefore there must be a margin of power over that required to actually lift the effluent to the required level. In the case of the pneumatic ejector such material is simply carried forward by the velocity of the water, without being subjected to violent action. In order to enable the suction pipe of such pumps to draw from the sump without becoming choked or obstructed with sticks, etc., the suction orifice consists of a slit, by which means it is claimed vegetable matter easily passes but excludes large objects that might choke the pump. It is an open question whether there is any appreciable loss from friction due to this form of suction orifice; but the difference between a plain termination of a circular pipe for suction purposes and the recognised standard bell mouth is well known. However, in raising crude sewage, hard and fast rules may often be abandoned without detrimental results, though it is as well not to travel too far from traditional practice, and all modifications should be as much as possible in accord with science.

Arrangements are made to automatically start and stop the motors by means of floats, actuated by the rise

and fall of the sewage. Thus, when the sump contains a certain depth of water the pump starts; when the water has fallen to a certain predetermined level the pump stops. The advantages of eliminating the friction in the rising main are very great; but we have to remember there is a certain amount of increased mechanical friction from running three or four sets of motors and pumps in place of one or two units. There is also the additional capital cost, increased maintenance and stores, and repairs in proportion.

The gravitation pumping mains also serve as sewers, and are, of course, kept constantly flushed. On the other hand, in countries where decomposition of the effluent sets in very rapidly, a number of sumps dotted about a city are open to objection from the sanitary point of view, and even some danger to employees.

Sumps: Dangers from Gas.

No matter what automatic devices may be employed for removing heavy objects, or type of catch-pit that can be raised to the surface, it becomes necessary at times for men to descend them and run the risk of losing their lives from foul gases. In semi-tropical climates these gases generate with great rapidity, and every hand employed, either cannot, or will not take those precautions of which he does not see the use.

Most engineers can give instances of loss of life from men descending sumps and manholes, even in cases where gas has never been suspected till the man has failed to reappear.

As an example, a new manhole had recently been completed which was connected to an ejector station. Neither the ejector nor the sewer was in use, but the manhole contained 3 feet or 4 feet of infiltration water.

The ejector was started, the water drained off, with a few discharges, and it was observed that the mason had left a brick on the benching some days previously. One of the men present descended to remove it, and his mate guarding the entrance happened to engage a friend in conversation. Wondering at the delay in the man's reappearance he looked down the manhole, and observed his comrade was prostrate at the bottom, and, though brought to the surface immediately, could not be revived.

Sumps: Dangers from Explosion.

At times it is also exceedingly dangerous to lower naked lights into manholes and sumps, and examples could be given of several men being killed and injured by a single explosion. Numerous sewage sumps should be avoided, especially in cities where they have to be covered in and do not have free ventilation. No drainage scheme which embodies dangerous features should be recommended if an alternative exists of equal merits, even at some saving in first costs.

Electric Motors.

The average type of electric motor placed in an underground chamber is often far from reliable. The damp atmosphere tends to corrode all bright surfaces, and if shocks occur, or there is a heavy overload, the motor may be seriously injured.

If large powers are required, a high voltage must be employed or the motor will be heavy and costly, and with high voltage there is always the danger of a fatal accident unless highly paid men are employed.

The very ease and simplicity with which a motor can be started and stopped breeds contempt for caution, and sooner or later a cleaner will accidentally touch a

live wire, neglect a safety switch, or make some other omission which will cost him his life. There is no warning—he is killed instantaneously.

A motor is a difficult and costly thing to repair, and as a rule it does not pay to keep a highly skilled man who is competent to rewind an armature that has been burnt out or turn up a commutator.

Motors' Reliability.

In well-built engine houses, motors will, of course, run for years, with practically no repairs and a minimum of attention; but for all that, when the critical time arrives, and the installation has to perform its work under unforeseen conditions (it may be once in a number of years), they are more liable to be put completely out of action by some trifling mishap. Unless an engineer has had various types of machinery under his personal supervision for long periods, it is not easy to appreciate this fact.

Let us take an actual example to demonstrate this contention. In the Cairo system of drainage, steam-driven compressors supply the ejector stations with compressed air. A separate plant, consisting of direct-coupled compound steam-engines and dynamos, supply current to electric motors for driving the main condensing-plant air and circulating pumps, besides supplying current to a motor pump situated in the grounds for renewing the water in the cooling pond.

In addition to the ejectors, a special storm-water pumping station is provided, containing motor centrifugal pumps, supplied with current from the Electric Light Company's mains.

For years the motors performed their work in a reliable and satisfactory manner. An exceptional rain occurred.

The streets for some hours were submerged with flood water. It was found necessary to bring the entire installation into service at the shortest possible notice. Water poured through the ejector-station covers, but the machinery continued to work, though half submerged, till the streets were drained.

The power house is a costly brick structure with gabled tiled roof. And the unusual downpour was the cause of some slight leakage, through the tiling. A few drops of water fell on one of the air-pump motors. The armature was immediately destroyed and the condensing plant put out of action, so the main engines had to exhaust to atmosphere. The storm-water motor pump was started, but after running a couple of hours the current failed, and it was found that the underground street cable had perished from being submerged and injured by subsidence. It is obvious that if, in place of ejectors operated by compressed air, motor pumps had been erected in the underground chambers or wells below the streets, they would have been put out of action in the first hour, and the whole drainage system would have been brought to a standstill.

Refuse in Sewage.

When unusual floods occur in large cities, immense quantities of refuse and mud are swept into the sewers, and if screens are used in sumps, they rapidly become blocked and the turbid mass surges over the top, carrying all before it into the pump suction, which may be completely choked.

In nine cases out of ten the most economical and satisfactory machinery for raising sewage is the simplest and most reliable, and the motive power, if converted into a secondary power and distributed over large areas,

should be applied as directly as possible to the work to be done, without the interposition of mechanical devices, and no corrosive surfaces or working parts should be brought into direct contact with an erosive fluid if it can possibly be avoided. The true sewage pump or apparatus, it must be remembered, should be able to raise and discharge a liquid or viscous fluid containing every conceivable substance and variety of refuse which may cause obstruction or destruction to machinery.

Like marine engines, all classes of sewage-raising apparatus can only be effectually tested in actual work over long periods.

CHAPTER III

MECHANICAL EFFICIENCY OF PUMPS AND EJECTORS.

Mechanical Efficiency.

From the foregoing chapter the importance of knowing the conditions under which a pump or ejector is working before drawing comparisons will be understood.

We will now examine the mechanical efficiency of the three pumps and multiple ejector system shown on the diagram, Plate XI. To ascertain the efficiencies it is necessary to determine the percentage of the power developed by the engine or motor that is actually converted into useful work. This is accomplished by dividing the pump horse-power by the indicated horse-power—in other words, the work done by the power employed to do it. The essential facts which must be determined to obtain accurate results are :

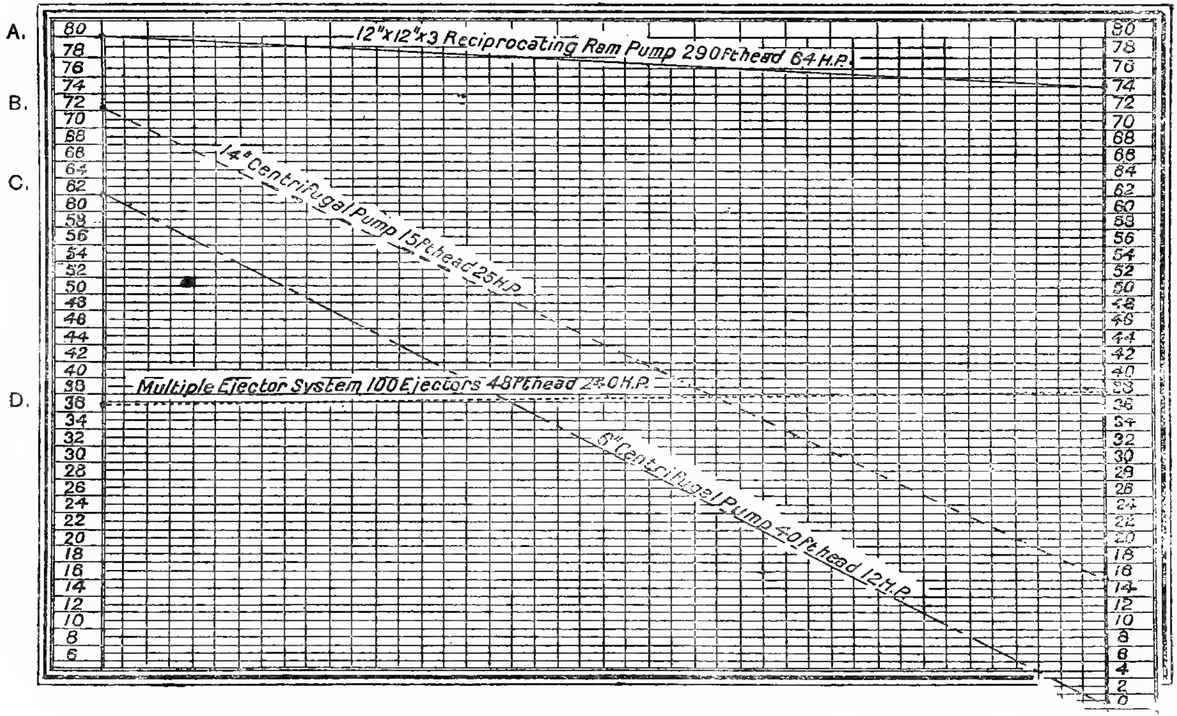
1. The indicated horse-power.

   This presents no difficulties, and the usual methods employed are not open to question, therefore the details will not be dealt with here.

2. The pump horse-power.

   That is the weight of water in pounds lifted per minute, multiplied by the height in feet to which the water is lifted, including frictional head divided by 33,000.

PLATE XI



MECHANICAL EFFICIENCY DIAGRAM

In each case these pumps and ejectors are good examples of the type they represent. They are designed and manufactured by well-known makers; but it is as well to withhold their names, as there is no desire to advertise one or penalise another.

They all discharge an effluent from the same source, and it would be difficult to find a more suitable instance for comparison.

Efficiency Diagram.

The diagram, Plate XI., shows at a glance the initial mean efficiency when the apparatus was first installed and after twelve months' use.

The following particulars should be noted. *A* and *B* both draw from the same sump. The effluent is gritty, heavily charged with refuse, and has at times almost the consistency of sludge from a settling tank.

The suction for *A* has a drop of 15 ft. and an 8-in. delivery main $2\frac{3}{4}$ miles in length. It is a three-throw single-acting ram pump, with a speed of 36 revolutions per minute, driven by a single-phase motor. It is fitted with multiple clear-way pump valves, and has a rated capacity of 500 gallons per minute.

B has a head on the suction and discharges through a 24-in. main $1\frac{1}{2}$ miles in length. It is driven by a direct-coupled motor with a vertical shaft and has a speed of 385 revolutions per minute.

C is for raising sludge from settling tanks. There is a head on the suction, and it discharges through an 8-in. main 130 yards in length, and has a speed of 1025 revolutions per minute.

D. The complete installation consists of 130 ejectors divided into 64 stations, with 23 miles of sealed-sewage rising mains and 28 miles of compressed-air mains;

but the power and number of those included in the tests will be given in full hereafter.

Calibrating Discharge.

In order to calculate these efficiencies it was necessary to ascertain the volume discharged.

In the case of the 12 in. $\times$ 12 in. pump (*A*) it was checked in the following manner.

A suitable masonry tank was built at the outfall. The main discharged into one end and the water escaped through a 9-in. pipe at the other. To measure the water the outlet was suddenly closed, the level of the water carefully recorded, and the time noted with a stop watch. When the water had risen to a predetermined level, the time was again taken. By taking the area of the tank and the height the water rose, it was possible to calculate the rate of discharge per minute of the pump. This test was repeated several times, with a difference of 1 or 2 per cent. only.

The discharge from the 14-in. pump (*B*) was determined from the rate the water was lowered in the suction well. As this pump drew water from the same sump as *A*, it was a simple matter to compare the time taken to lower the water from one level to another, by the two pumps. The initial efficiency of the 6-in. pump (*C*) was supplied by the contractor, and the ultimate efficiency, when after a year's work the pump practically ceased to discharge and was dismantled.

The method of ascertaining the discharge of the ejectors (*D*) is given in detail below.

Ejectors: Capacity and Discharge.

The capacity of a pump can be determined from the volume of water displaced by the ram or plunger at

each revolution. A meter can also be utilised for the purpose, but the extra expense is seldom incurred in a sewage installation.

However, there is no difficulty in shop tests and on official trials in determining the volume discharged with sufficient accuracy for all practical purposes; but the pneumatic ejector is on a different footing.

What is the capacity of an ejector?

There is no ram or plunger from which to calculate the volume of the liquid displaced, but a highly compressible fluid, subject to variation in volume according to pressure. Let us assume an ejector is rated at 50 gallons. That is to say, it should discharge 50 gallons from the time the compressed air is admitted till the exhaust opens. The question is, under working conditions, Is the discharge uniform? Is it more? Is it less?

Authorities do not agree on this vital subject. Hence the efficiency of the ejector is often a matter of controversy.

One authority questions the propriety of calculating the sewage discharged, when taken as the product of the ejector capacity in gallons. On the other hand, another authority considers that it is difficult to get anything more exact for measuring a volume of water; while a third authority calibrated a 50-gallon ejector and obtained a discharge of 38 gallons!

In view of such conflicting opinions, the author makes no apology for giving concise details as to how the capacity and discharge of the ejectors was determined for the efficiencies shown on the diagrams.

Calibrating Ejectors.

There are three methods of calibrating the discharge of ejectors:

1. By calculating from the interior measurements the capacity of the ejector body.
2. By weighing the actual volume of liquid expelled at each stroke.
3. By passing the discharge through a water meter of suitable design.

Obviously if it is possible to pass the sewage through a meter of known accuracy, the result from 1 and 2 is immaterial. But as far as the author is aware, there is no instance on record where such means have been available. The figures now given are compiled from investigations carried out over several years from time to time as opportunity offered. The design and size of the ejectors now given correspond with those shown on Plate IX.

Discharge Table

Capacity and Discharge of Ejectors

Index Letter.	Size, Galls.	Particulars.	Cubic Feet.	Gallons.	Excess per Cent.
A	500	From the internal diameter of the spherical body, not including base .	87·11	540·56	8·11
B	300	From interior measurements at water level after discharging and filling .	55·65	347·25	15·75
C	250	From the internal diameter of the spherical body not including base or float chamber .	44·60	275·30	10·12
D	150	Do. do.	28·73	176·30	17·53
E	100	Do. do.	18·81	114·37	14·37
F	50	From interior measurements with allowance for base and float chamber	9·81	58·25	16·50
G	500	By weight of water expelled from three discharges plus 1 per cent. for leakage and error .	Kilos. 2291·57	505·06	1·01
H	250	Do. do.	1155·53	254·68	1·87
J	50	Do. do.	251·40	55·41	10·82

Note.—In the case of *A*, *C*, *D*, *E*, *F*, three gallons have been deducted to allow for the internal weight.

From these figures it does not appear that the various sizes are made with a uniform margin for possible loss or excess discharge on the rated capacity. In case *B* the capacity was gauged as follows, and it will be noted

from the design, Plate IX., that it is the only size of those given in which such a method can be adopted.

Calibrating Ejectors by Measurement.

The ejector was under ordinary working conditions. Immediately after a discharge the delivery sluice valve was closed. The cover was then prepared for rapid removal by unscrewing the nuts. As the ejector filled, the air stop valve was closed, and the inlet sluice valve was screwed down till half a turn open. Immediately the float rose the inlet sluice valve was closed, the cover removed, and the height of the water measured. The cover was then replaced, the delivery sluice valve opened and the ejector discharged, and the valve again closed. Finally, the cover was removed and the level to which the water had fallen was measured.

In daily automatic working the sluice valves are always fully open, and, provided the fellow ejector is still discharging, the water continues to rise, because the filling of the ejector is stopped by the admission of the compressed air and not by the float rising. It must be remembered the ejectors can fill together, but they cannot discharge together.

It is obvious the discharge can vary from this cause alone. Again there is an appreciable pause between the rising of the float and the pressure of the air on the liquid, even with a single ejector working. Also when the ejectors discharge through long mains, the kinetic energy of the water tends to over discharge. On the other hand, in course of time fouling of the ejector body and floating matter tend to lessen the discharge.

Calibrating Ejectors by Weight of Water Expelled.

There is no more accurate method of calibrating the

contents of an irregular vessel than by the weight of the liquid it contains. But the difficulty of reproducing working conditions, automatic actions, and detecting leakage, leave a degree of uncertainty attached to the operation in some instances.

The method adopted in the case of *G*, *H*, *J* was as follows.

The delivery sluice valve on the rising main, some 30 ft. from the ejector, was closed and the reflux valve cover fitted with a 2-in. W.I. pipe. A 50-gallon tank was then placed on a portable weighing machine and arranged so that the water could be drawn off from the ejector directly into the tank and weighed.

In the case of the 50-gallon ejector (*J*) this was done in a minute or so, and the loss must have been insignificant; but with the 500-gallon ejectors (*G*) the operation took from twenty to thirty minutes, and it is at once apparent that though the loss in *J* approximated to working conditions the loss in *G*, that is, the percentage of water that failed to reach the tank would be unduly magnified. It must be borne in mind that in ordinary working conditions both these ejectors discharge in half a minute, and there is no reason to assume that the slip in one is greater than the slip in the other.

In the case of these ejectors a certain number discharged through a 33-in. Venturi meter, thus affording a unique opportunity for checking the discharge under actual working conditions over prolonged periods.

Ejector Discharge compared with Venturi Meter.

The Venturi meter is a well-known standard instrument of accepted accuracy, and the only type, by reason of the absence of working parts, through which crude sewage can be measured with success.

The following table is of singular interest.

Ejector and Venturi Meter Discharge in Cubic Metres

Time.	No. of Ejectors.	Capacity. Gallons.	Discharge. Cubic Metres.	Ejector. Total. Cubic Metres.	Venturi. Cubic Metres.	Excess per Cent.
12 hours	10	500	5,738			
	2	250	550			
	2	50	270	6,558	6,870	4·37
24 ,,	10	500	10,857			
	4	250	806			
	4	100	592			
	4	50	37	12,292	12,900	4·70
24 ,,	5	500	6,024			
	2	250	476			
	2	100	19			
	1	50	8	6527	6,939	5·94
31 days	36	500 to 50	..	529,760	554,800	4·51

It will be observed that this table practically amounts to a comparison between the Venturi meter and the 500-gallon ejector owing to the insignificant contribution from the smaller sizes. It is interesting to compare these figures with the measurements by weight, and it will be seen that the suggestion put forward to account for the difference in margin between the 50 and 500 gallon ejectors is not without foundation. These figures show that the ejectors in actual work discharge more than their rated capacity according to the volume registered by the Venturi meter.

Chemical Test of Venturi Meter.

The following figures show the results of a chemical test by qualified officials, of the rate of flow immediately above the meter:

Venturi Meter.	Chemical Test.	Excess.
694 cub. metres per hour.	705 cub. metres per hour.	1·6 per cent.

That is to say, the rate of flow registered by the meter was lower than that recorded by the chemical test. For the efficiency trials the ejector discharge was taken at 4·75 per cent. in excess of the rated capacity, and subsequent records show that this is not excessive.

Pressure Gauge Errors.

The height to which the weight of water is lifted—in other words, the 'working head,' including friction in the mains—is determined by the pressure recorded on the gauge attached to the ejector body. Few gauges are precisely accurate, and at working pressures of 100 and 200 lbs. per sq. inch a slight error is of little consequence; but with pressures that range from 10 to 25 lbs. per sq. inch, a small error is often equal to 8 per cent. or 10 per cent.

The ordinary Bourdon gauge is a simple apparatus, and if accuracy is desired it is imperative to adjust each gauge before use by means of a testing machine. The Crosby tester is a standard dead-weight apparatus, and the following table shows the error of each gauge tested by a machine of this type:

Error of Gauge at Mean Working Pressure
lbs. per Sq. Inch

Ejector Station.	Near Side.	Off Side.	Ejector Station.	Near Side.	Off Side.
32	−0·50	−1·25	33	−1·00	−1·00
54	−1·50	−1·25	27	−1·00	−2·00
25	−1·50	..	5	−1·00	..
25 S.W.D.	−1·00	−0·75	15	−1·00	..
55	−2·25	−1·50	26	−1·50	−1·00
31	−1·25	−1·00	75	..	..
60	..	−1·00	71	−1·50	−0·50
65	−0·75	−1·00	2	−0·75	−1·00
67	−0·25	..	23	+0·25	..
58	−1·00	−1·50	23*A*	−1·00	−2·25
57	−1·50	−1·50	23*B*	−1·25	−1·00
37	−2·50	..			

It will be noticed of these 46 gauges 36 register at too low a figure, 9 are correct, and 1 is too high. It will be readily understood from the above table that in calculating the work done by a series of small engines, distributed over a wide area, that inaccurate records will in the aggregate amount to a serious error, and the importance of correct facts cannot be overestimated.

Air Mains: Proportional Loss.

In an ejector system, especially of great extent, the leakage from the air mains is the same whether a full-power trial or only one-sixth of a full-power trial is run. Hence it follows that to arrive at the correct efficiency of a system, a proportion of the air-main losses must be deducted according to the power developed.

The following table shows a series of air-main tests :

AIR-MAIN TESTS

No.	Date.	Press. in lbs.	Loss in hour. Lbs.	Loss per Cent.	Revs. p.m. to make good.
A	May 4, 1915 .	50·00	5·00	10·00	..
B	May 3, 1916 .	23·50	3·50	14·80	9·50
C	Aug. 10 ,, .	23·50	4·00	17·00	11·70
D	Dec. 4 ,, .	24·00	6·50	27·00	18·07
E	Jan. 23, 1917 .	24·00	4·50	18·75	12·53
F	Feb. 3 ,, .	22·50	4·00	17·70	10·90

With the exception of test *A*, none of these results are good, as little recaulking had been done. There is no difficulty at these low pressures in maintaining the air mains sufficiently tight for an ejector efficiency of 40 per cent., and without doubt it pays to reduce leakage to 5 per cent. or 6 per cent.

AIR-MAIN TESTING.

To determine the amount of leakage from the air mains, all the ejectors are stopped. The compressing engines are then stopped and the pressure recorded. When the pressure has fallen to a predetermined figure, the engine is restarted. By recording the number of revolutions taken to make good the lost pressure, and dividing the total by the duration of the test in minutes, the I.H.P. absorbed by leakage can be determined. It must not be overlooked that the compressed air is simply a method of transmission of the power employed to do the work.

Ejector Trials: Conditions.

It is manifest that owing to the nature of the working fluid, an ejector system, to give the best results, must be run with a minimum air pressure and a maximum volume of water—conditions which it is practically impossible to obtain in a multiple-ejector system on first being installed. With a single-pumping installation it is easy enough to by-pass the liquid to the sump for trial purposes.

Ejector Efficiency Diagram.

Plate XII. shows graphically how an ejector system maintains efficiency. The first and second results are 12-hour trials, the next two 24-hour trials, and the last two over periods of four weeks each. It is these last two trials that are of special interest, not only from the long period over which they are taken, but owing to the huge volume of water raised and the large number of ejectors included. To ensure the existence of ordinary working conditions, no intimation was given to the daily inspection staff, but frequent checking to see that the ejector counters were in good order. The details of the ejector powers for the October test were 49 ejector stations, containing 100 ejectors.

Ejector Efficiency Trial.

May 10, 1916, 6 A.M. *to* 6 P.M.—12 *hours*

No. 3 engine I.H.P.	110·21	Vacuum . .	27·6
Steam pressure .	154·10	Air pressure .	20·9
Revs. per minute .	84·69	Steam per I.H.P.	
Steam temperature .	477·20	per hour .	15·9

Fifteen ejector stations were included in this trial.

EJECTOR RESULTS

No. of Ejector.	Capacity. Gallons.	Revolutions.	Gallons discharged.	Head in Feet.	Pump Horse-power.
32	500	387	193,500	40·54	3·301
54	500	1,033	516,500	47·42	10·308
25	500	863	431,500	42·15	7·654
25 S.W.D.	500	200	100,000	42·15	1·773
55	250	681	170,250	30·53	2·187
31	500	276	138,000	32·38	1·907
60	50	1,542	77,100	36·03	1·184
37	100	854	85,400	30·49	1·095
33	300	360	108,000	44·69	2·031
27	100	1,085	108,500	43·26	1·975
5	500	253	126,500	46·10	2·454
15	250	301	75,250	39·15	1·239
75	150	79	11,850	43·89	0·218
23	250	226	56,500	41·62	0·989
23*B*	100	202	20,200	38·62	0·328
			2,219,050		38·643

Venturi meter correction $=4{\cdot}75$ per cent.

Therefore P.H.P. $=40{\cdot}478$.

Difference of pressure of 1 lb. in receiver $=0{\cdot}30$ I.H.P.

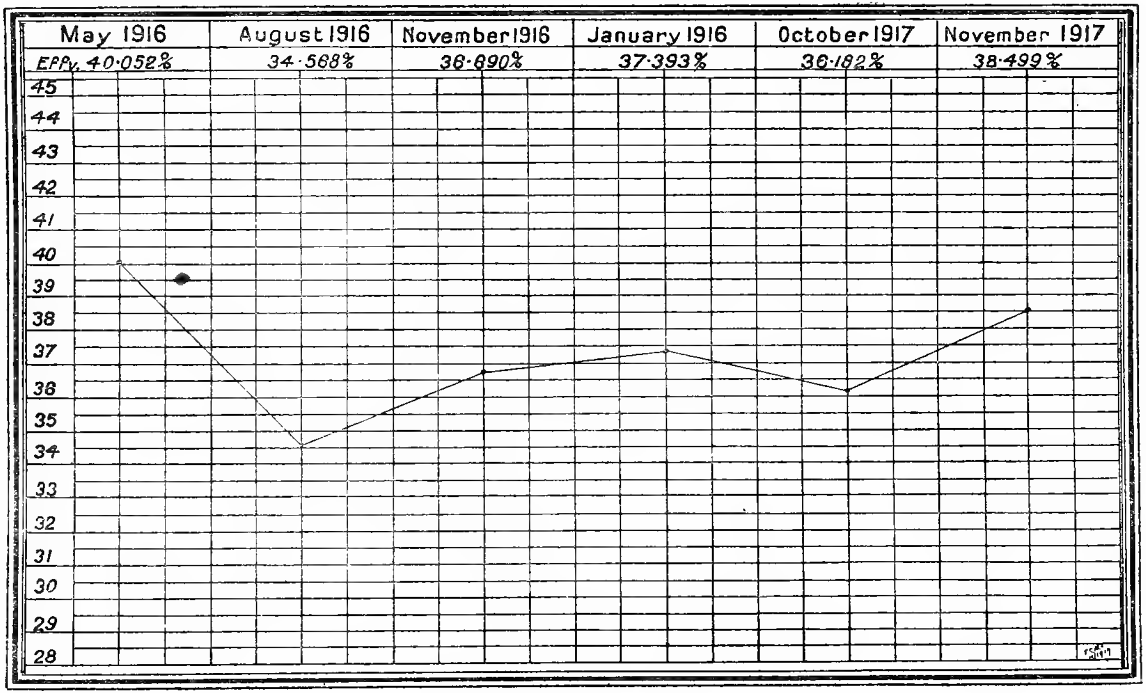
Therefore I.H.P. $=109{\cdot}91$.

Overall efficiency, including all mains $=\dfrac{40{\cdot}478}{109{\cdot}91}=36{\cdot}828$.

Two-thirds of air-main leakage $=8{\cdot}847$ I.H.P.

Therefore efficiency with proportional loss $=\dfrac{40{\cdot}478}{101{\cdot}063}=40{\cdot}052$.

PLATE XII



Ejector Efficiency Diagram

EJECTOR EFFICIENCY TRIALS: TWELVE HOURS.

Here is the result of an efficiency trial, including 14 stations for 12 hours:

August 7, 1916, 6 A.M. *to* 6 P.M.

No. 3 engine I.H.P. .	119·11	Vacuum . . .	26·0
Steam pressure .	145·3	Air press. at receiver	20·70
Revs. per minute .	83·5	Steam temperature .	480·8

Steam per I.H.P. per hour, 15·32 lbs.

Ejector Pump Horse-powers

No. of Ejector.	Capacity. Gallons.	Revolutions.	Gallons discharged.	Head in Feet.	Pump Horse-power.
32	500	365	182,500	40·70	3·126
54	500	780	390,000	30·26	4·966
25	500	962	481,000	38·78	7·850
25 S.W.D.	500	185	92,500	24·27	0·944
55	250	485	121,250	27·83	1·420
31	500	238	119,000	32·82	1·643
60	50	1,193	59,550	37·30	0·936
33	300	405	121,500	46·10	2·357
27	100	1,362	136,200	34·18	1·959
5	500	578	289,000	42·73	5·197
15	250	286	71,500	37·42	1·126
26	250	249	62,250	43·42	1·137
75	150	95	14,250	45·41	0·272
23	250	490	132,500	43·58	2·246
			2,263,100		35·179

Venturi meter correction = 4·75 per cent.

Therefore P.H.P. =36·850.

Overall efficiency, including all mains $=\frac{36{\cdot}850}{119{\cdot}110}=30{\cdot}537$.

Two-thirds of air-main leakage =12·51 I.H.P.

Therefore efficiency with proportional loss $=\frac{36{\cdot}850}{106{\cdot}60}=34{\cdot}568$.

Ejector Efficiency Trial

October 1 *to October* 31, 1917

No. 1 and 2 engines

I.H.P. . .	214·82	Steam pressure .	160 lbs.
Revs. per minute .	150·22	Vacuum . .	22 inches

No. of Ejector.	Capacity.	Revolutions.	Gallons discharged.	Head in Feet.	Pump Horse-power.
32	500	30,473	15,236,500	43·89	4·540
54	500	23,914	11,957,000	46·20	3·749
25	500	65,539	32,769,500	46·20	10·278
25 S.W.D.	500	53,987	26,993,500	34·65	6·350
55	250	24,048	6,012,000	32·34	1·320
31	500	11,261	5,630,500	32·34	1·237
60	50	68,145	3,407,250	48·51	1·122
65	250	37,460	9,365,000	39·27	2·497
67	50	95,008	4,750,400	43·89	1·416
58	100	58,505	5,850,500	46·20	1·835
69	150	59,985	8,997,750	46·20	2·822
57	100	7,211	721,100	39·27	0·193
59	250	26,408	6,602,000	43·89	1·966
53	250	4,817	1,204,250	43·89	0·352
68	250	24,545	6,136,250	48·51	2·020
63	100	3,205	320,500	46·20	0·100
61	100	6,544	654,400	46·20	0·206
62	100	42,174	4,217,400	46·20	1·323
37	100	9,838	983,800	32·34	0·216
33	300	42,107	12,632,100	48·51	4·160
27	100	32,923	3,292,300	39·27	0·878
5	500	17,210	8,605,000	48·51	2·834
14	250	41,657	10,414,250	50·82	3·592
15	250	11,142	2,785,500	48·51	0·917
22	150	193	28,950	48·51	0·010
17	100	1,163	116,300	41·58	0·033
26	250	11,855	2,963,750	46·20	0·930
39	100	8,149	814,900	43·89	0·243
30	150	1,521	228,150	41·58	0·007
28	100	4,408	440,800	43·89	0·014
6	150	34	5,100	46·20	0·002
51	500	9,825	4,912,500	46·20	1·540

EJECTOR EFFICIENCY TRIAL (*continued*)

October 1 *to October* 31, 1917

No. 1 and 2 engines

I.H.P. . .	214·82	Steam pressure .	160 lbs.
Revs. per minute .	150·22	Vacuum . .	22 inches

No. of Ejector.	Capacity.	Revolutions.	Gallons discharged.	Head in Feet.	Pump Horse-power.
18	250	17	4,250	43·89	0·002
66	150	61	9,150	41·58	0·003
56	500	10,262	5,131,000	46·20	1·610
75	150	7,139	1,070,850	32·34	0·236
71	250	2,171	542,750	43·89	0·162
72	250	612	153,000	43·89	0·046
23	250	40,748	10,187,000	46·20	3·195
23*A*	250	3,263	815,750	46·20	0·256
23*B*	100	75,594	7,559,400	46·20	2·370
1	50	813	40,650	43·89	0·122
2	50	31,279	1,563,950	43·89	0·466
3	50	22,586	1,129,300	43·89	0·337
12	100	310	3,100	41·58	0·009
4	50	14	700	41·58	
73	250	6	1,500	..	
24	150	9	1,350	46·20	0·001
41	50	4	200	..	
64	150	..	..	..	
			227,291,000		68·717

Venturi meter correction =4·75 per cent.

Therefore P.H.P. =71·981.

Overall efficiency, including all mains $=\frac{71\cdot981}{214\cdot824}=33\cdot506.$

One-third of air-main leakage =15·037 I.H.P.

Three ejector blow-throughs = 0·863 I.H.P.

Therefore efficiency with proportional loss $=\frac{71\cdot981}{198\cdot922}=36\cdot185.$

EJECTOR TRIAL: REMARKS.

The pump horse-powers given leave little room for question, neither is the indicated horse-power open to much doubt; but there are losses detrimental to the best efficiency which can only be enumerated and not calculated. And it may be stated definitely that the true efficiency is considerably higher, probably reaching 40 per cent. If only such favourable conditions were permitted, as invariably exist on pumping-engine trials, there is no reason why even higher figures should not be obtained. However, it is preferable to give actual results than figures based on assumption.

From recorded tests the estimated air-main loss was not less than 21 per cent. A considerable volume of air was used for auxiliary purposes. There was also loss in changing engines, and on numerous occasions during the month the engines were overtaxed, and two forced stoppages took place. The circulating water for the condenser was inadequate and often 112° F.; also many other minor faults existed which would not be tolerated on an official trial.

EJECTOR AND PUMP TRIAL COMPARED.

The feature of the above trial is the immense number of small powers, and that two-thirds of full power was employed continually over so long a period under ordinary conditions. If pumps were substituted for ejectors under such conditions, friction would absorb nearly the whole power, yet it is often the practice to compare the efficiency of such an ejector installation with that of a single-pumping plant of equal horse-power.

It is manifest a single large power must give the higher

mechanical efficiency, especially when every favourable condition can be provided.

The reciprocating ram pump has been brought to an extraordinary degree of perfection, and in order to illustrate the immense difference which still exists in mechanical efficiency between such a pump and an ejector system even after making every allowance, the results of two trials are given below.

The engine was of the quadruple expansion type, steam cylinders, 17 ins. × 27 ins. × 33 ins. × 49 ins. with crank and flywheel, coupled direct to a three-throw single-acting ram pump, 21½ ins. × 3 ft.

Reciprocating Pump Trial

Trial.	*A*	*B*
Duration of trial	12 hours.	23·75 hours.
Revolutions per minute	23·42	23·5
Total head	144 ft.	183·73 ft.
Steam pressure	198·01 lbs.	200·00 lbs.
Steam temperature	522° F.	518° F.
Vacuum	25·82	23·37
Steam per I.H.P.	9·75 lbs.	10·18 lbs.
Pump horse-power	140·94	180·27
Indicated horse-power	155·08	195·4
Mechanical efficiency	90·88	92·8
Gallons raised per minute	3229·88	3240·8
Total in gallons raised	2,325,513	4,618,140

The pump was discharging the same effluent after screening as the ejector. In considering the great difference it must be pointed out the efficiency of the air-compressing engines was very much less. With an efficiency of 90, which the leading makers guarantee at the present day, the ejectors would not fall so far behind as disclosed by these tests.

There is inevitable loss in compressing air, but at the low pressure used in ejector systems this does not amount to a serious figure. The principal cause is preventable leakage and the type of compressing machinery installed.

It is clear an ejector system cannot attain the efficiency of a single pumping installation ; but it must not be supposed that 92 per cent. is maintained in daily practice. Probably the efficiency of the 12 ins. × 12 ins. (*A*) pump in Plate XI. is as high if not higher than 90 per cent. of such pumps in use raising crude sewage.

Summary of Efficiencies.

To sum up : the high-class reciprocating pump is by far the most mechanically efficient device in use.

The centrifugal pump, though initially efficient, rapidly fails.

The pneumatic ejector, commencing at a lower efficiency, does not deteriorate.

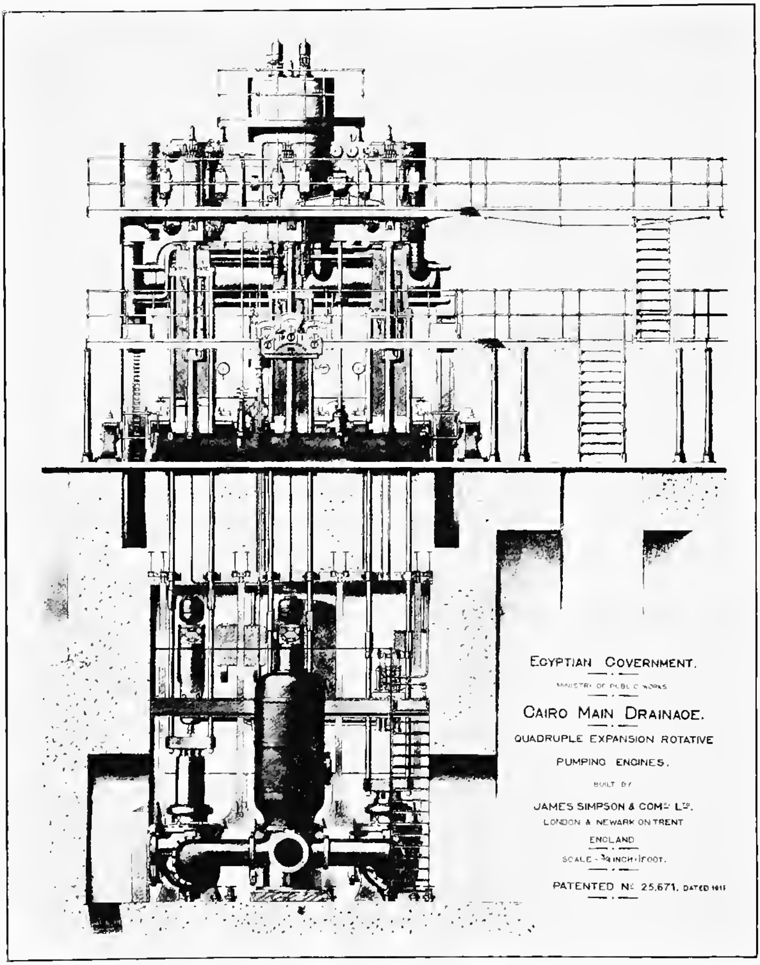
The merits of one system compared to another will always be a matter of controversy. Much depends upon the point of view from which they are considered. But in the majority of sewage undertakings there is little doubt which is the best method to adopt from the mechanical standpoint, if the evidence and observation here set out are carefully weighed and analysed.

It cannot be too emphatically stated that it is the mechanical efficiency which a power device maintains, and not that which it can attain when first installed, that should be kept in view.

There is no class of machinery in which an official trial is apt to give more misleading results, than that employed in raising crude sewage.

Irrefutable evidence, based on long periods of working, should alone be taken as conclusive.

PLATE XIII



VERTICAL STEAM PUMPING ENGINE

CHAPTER IV

COMMERCIAL EFFICIENCY

To compare the commercial efficiency of a pumping plant to an ejector system, it is necessary to give a brief description of what they consist. We have to consider the capital cost, construction, supervision, and maintenance. For the present, only the essentials will be taken and the results analysed, the details being held over to a later chapter.

Pumping Installation: Summary.

A large pumping installation will consist of four or five units of 150 horse-power apiece, and may be either direct-acting or rotary crank and flywheel engines, actuating three-throw single-acting ram pumps. Such machinery will be suitable for raising eight or nine million gallons of sewage per day to a height of 130 feet to 200 feet, according to the normal or maximum volume passing through the main.

A fine example of a large vertical steam pumping engine for raising crude sewage is shown in Plate XIII.

This is a quadruple expansion rotative engine with two flywheels. The general design is of the marine type, with an open front and massive supporting columns. The engine bed-plate is placed on the same level as the engine-house floor, and there are three stages, one above the other, to gain access to the upper part of the engine.

There are four steam cylinders, three side by side and the fourth in line above the centre cylinder.

It will be observed there are three single-acting pumps, and the left-hand pump shows the ram at the top of its stroke. Each of these rams is directly coupled to the piston-rod cross head. The cylinder valves are operated by bevel gear and shafting driven from the main crank shaft. Such engines as these have a great range of speed, and will run with a fuel consumption of only ten lbs. of steam per indicated horse-power per hour.

It will be observed the foundations consist of a solid mass of concrete, and a chamber in the base of this mass forms the suction wells from which the pumps draw.

A pumping installation may be divided as follows :

1. Engine and boiler house, chimney shaft.
2. The pump chambers and sump.
3. The screening chamber.
4. The machinery, engine and pumps.
5. The rising main.

Assuming the engines are of the vertical triple expansion type, the bed-plate will be at floor level, the head of the supporting columns the first stage, and a second stage for access to the top of the engine. As head room must be given for the travelling crane, it is clear that the building will be massive and of great height. Below the floor the condensers, air pumps, and feed pumps will be arranged, and below this again the pump floor, in which are bedded the anchor bolts. In nine cases out of ten, sewage pumps require deep foundations, as the sump from which they draw the effluent must be below the level of the sewer outfall, and the suction of the pump must again be provided with some depth to draw from.

Sump.

The sump or suction chamber will be directly below the pumps, and as the whole weight of the engines rest on this structure, it must be of great massiveness and strength. In water-logged ground a sump of this description is an extremely costly part of the work to build, and will often absorb the greater part of the building estimates. The necessity of having this sump beneath the pumps in large units is very real, as the first condition to successful working is to have the suction pipes as short as possible.

Screening Chamber.

This chamber has also to be of great depth and in duplicate, or rather bisected by a wall, so one half can be cleaned while the other is in use. The screens themselves are provided with rakes attached to endless chains, for cleaning the bars of refuse and raising it to the top, while a chain of dredging buckets has also to be provided for raising solids from the bottom. Such machinery is usually run by motors, and a building must be erected to cover them. Trolleys and rails will be required to remove the screenings as fast as they are raised. The wear and tear on this gear is extremely severe, but this cannot be avoided. This section is indeed costly to build and costly to maintain.

Auxiliaries.

An ample fresh-water supply must be arranged; possibly a well has to be sunk and a cooling pond for the condenser circulating water; engines and dynamos for driving the motors for the screening chamber, air compressors for filling the air vessels on the main pumps, and also a complete workshop for carrying out repairs.

Rising Main.

The rising main may of course be of any length. Let us assume an average of ten miles. It should be of such a diameter that the liquid maintains a velocity of 3 feet per second under normal working conditions. At times of maximum flow, when reserve pumps are kept running to deal with flood water, there will of course be excessive frictional head, but this cannot be avoided, as it would not be economically sound either in capital cost or maintenance to lay a larger pipe than suitable for normal conditions. Neither is there any economy in laying two mains. Friction would be increased, and reduction in capacity from internal fouling would be greater. Again, double the number of valves and fittings would be required.

Cast-iron spigot and socket pipes are to be preferred, though steel, specially coated, and reinforced concrete have claims to be considered under favourable circumstances. The main will be divided into sections, according to grades, and each section will require sluice valves, scour pipes, air valves, etc., arranged in suitable positions.

Working of Pump Station.

The power is the steam generated in the boilers and conveyed to the steam cylinders for actuating the engine. The main sewer will discharge into the screening chamber. Heavy matter, stones, and sand will sink to the bottom to be raised by the dredging buckets. Sticks and floating material will lodge against the bars of the screens and be removed by the chain rakes, and the liquid will pass to the sump from which the suction pipes draw their supply. Each pump will have a separate suction, but may discharge a common main. The efficiency of

this operation of passing the sewage from the sump to the rising main will depend entirely on the pump valves, provided the suction is free from leakage, and the pump is so designed that it is free from air pockets.

Pumping Installations: Advantages and Merits.

The outstanding advantage of a single pump-station is that the work to be done is concentrated, therefore the maximum use can be made of the motive power. An installation of this description is the most mechanically efficient method of raising sewage known, as has already been shown. And the reason is :

1. That the motive power and the work to be done act on one another without the interposition of a secondary power or mechanical motion beyond the reciprocating action of the steam piston and the pump ram connected by the piston rod.

2. That it is possible to convert the maximum percentage of the motive fluid into useful work with a minimum of loss from dissipation and friction.

The initial pressure of the steam is absorbed and given out in a perfectly uniform manner by means of a suitable flywheel or compensating cylinders, which are balanced by differential accumulators and the pressure in the rising main. Though so mechanically efficient we cannot avoid bringing the working parts of the pump, like valves and pump rams, in contact with the erosive fluid, and though they can be kept efficient it is only at some labour and expense. The screening chamber, and constant work connected therewith, is all labour and repair due to the pump. Commercially what we gain in the power end we are liable to lose in the water end, without able supervision. The greater the pressure the more efficient is this method compared to any other, but there

is a limit in the downward scale, when it is less costly to adopt other means though mechanically less efficient. The nature of the fluid and the head of water it is desired to pump against are the deciding factors.

Ejector Installation: Summary.

At first sight, compared to a compact pumping plant, an ejector system is a complicated network of inefficient units, that would appear to require an immense staff and endless repairs. An installation that will raise eight or nine million gallons a day to a height of 50 feet, may be divided up as follows for the purpose of comparison :

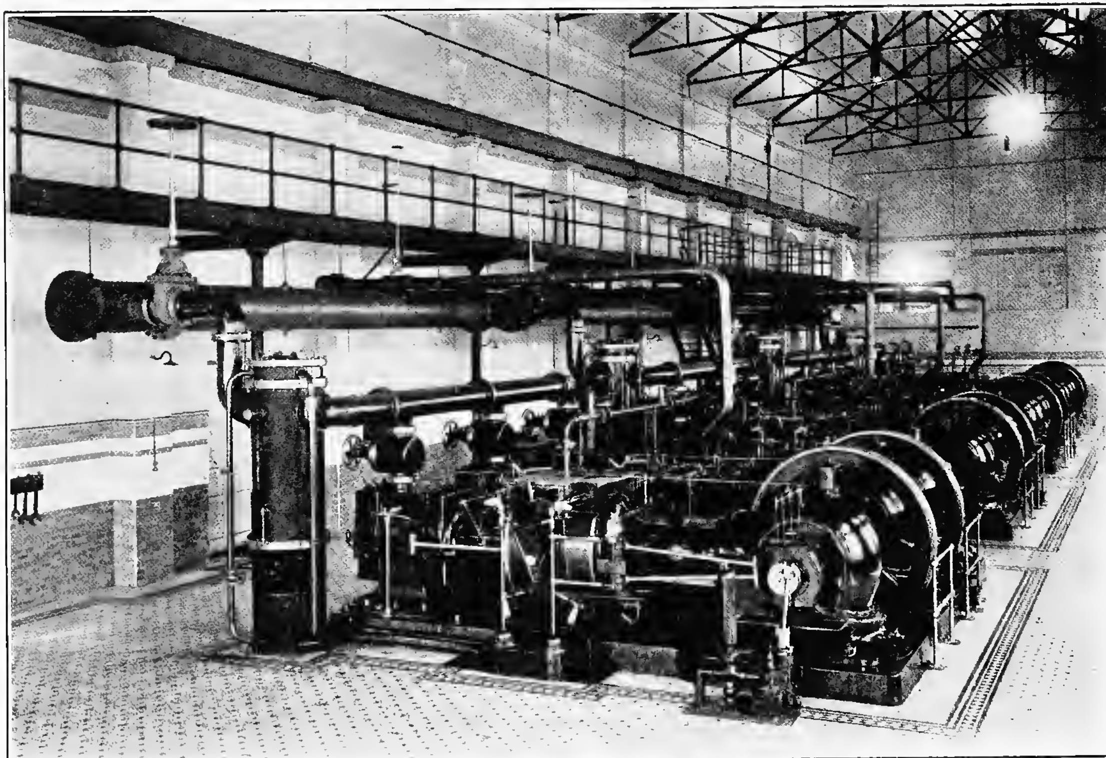
1. Engine and boiler house, chimney shaft.
2. Engines and air compressors.
3. A number of ejector stations.
4. Distributing air mains.
5. A number of sealed sewage mains.

Assuming the engines for compressing the air are of the triple expansion horizontal type, though the vertical type will take up less room, a building of less height and massiveness will be required than for the pumps, and a basement only will be necessary.

A good example of an installation of this type is shown in Plate XIV. and Plate XV. Though they are extravagant in floor space they are economical in head room. Compared to a vertical steam pump we have only two 'floors' in place of five, and there is less labour in attending to the engines.

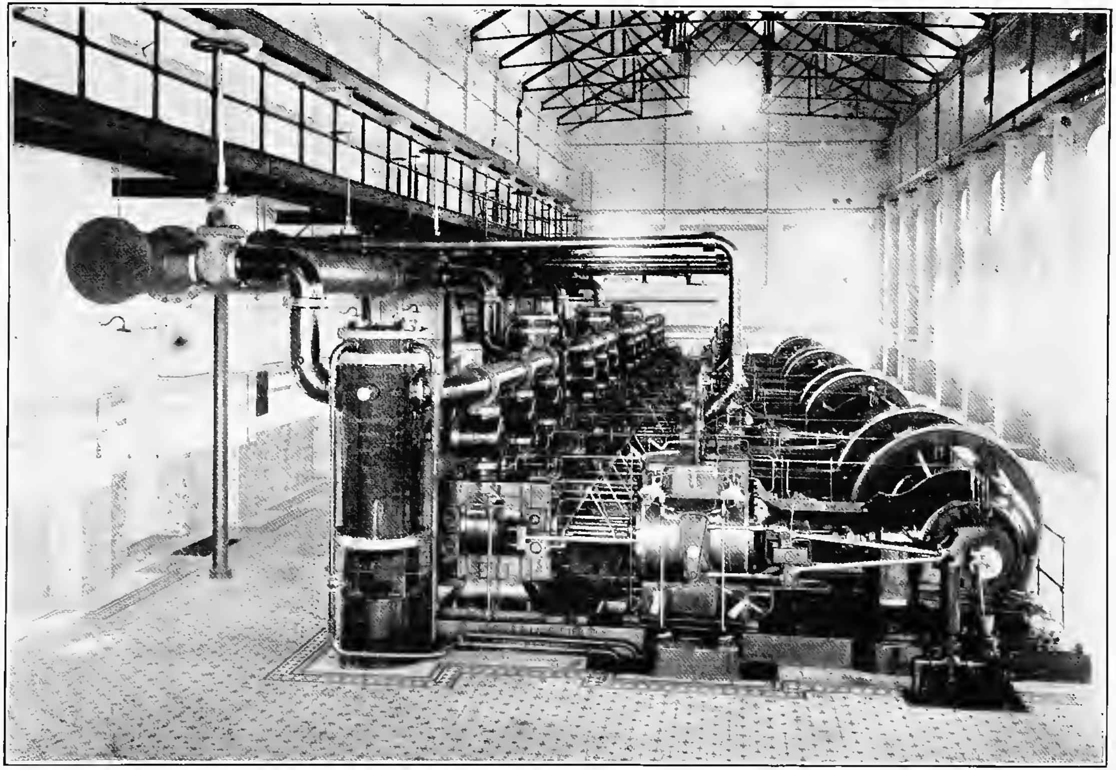
The boilers will probably be of the water-tube type, and the usual auxiliaries, consisting of electric light engines, economisers, cooling pond for the circulating water, will complete the station. An ample water supply must be provided either from the town water supply or other source.

PLATE XIV



Horizontal Air-compressing Engines

PLATE XV



Horizontal Air-compressing Engines

EJECTOR STATIONS.

The number of the ejectors and the chambers in which they are placed will depend on the magnitude and levels of the area to be sewered. Assuming these chambers are cast-iron tubbings, they will range from 8 feet to 20 feet in diameter, and, with few exceptions, are sunk directly beneath the streets. Each tubbing will contain two or more ejectors, the details of which have been explained at length in Chapter II.

AIR MAINS.

Sixty ejector stations will require about twenty-eight miles of cast-iron spigot and socket air main, ranging from 2½ to 21 inches in diameter, laid 2 or 3 feet below the surface of the street. Air valves, drain cocks, surface boxes must also be provided.

SEALED SEWAGE MAINS.

These rising mains from the ejector stations will amount to another twenty-five miles of cast-iron spigot and socket pipe, with the usual accessories. In many cases they can be laid in the same trench as the air mains, thus avoiding some expense in construction.

WORKING OF EJECTOR SYSTEM: COMPRESSING AIR.

The power is the steam generated in the boilers and conveyed to the steam cylinders for actuating the engines. The air to be compressed is cooled by an open air evaporating device, consisting of a circular masonry chamber, in which roofing tiles are arranged on a suitable frame beneath a water sprinkler. Beneath this roof the air intake is situated. From this device the air passes by means of a 36-in. pipe to ducts beneath the compressing cylinders, which are jacketed and cooled by a pump

attached to the crank shaft of each engine. From the compressor the air passes through a multi-tubular after-cooler, and thence into the collecting main, which discharges into two steel receivers of sufficient capacity to maintain a uniform flow. From these receivers the air may flow through a meter to the distributing main for working the ejectors.

Alongside each ejector is situated a street manhole, from which the sewage gravitates into the body of the ejector, and is automatically forced into the rising main every few minutes.

Ejector Installations: Advantages and Merits.

The outstanding advantage of the ejector system is that we have no sump or screening chamber. But we have to employ a secondary power—that is, the motive power, instead of being applied directly to the work to be done, has to be converted to another power before it can be so applied. In this process we sacrifice efficiency. Again, owing to the nature of the secondary power—that is, the compressed air—the process of conversion at the higher pressure, which would be required to do the work that is done by the reciprocating pump, is wasteful and costly. The ejector, it must be borne in mind, corresponds to the water end of the pumping engine, but it may be located miles away from the steam end. The compressed air is simply the medium of transmission.

In the ejector, however, the secondary power is applied directly to the work to be done without the interposition of mechanical motion. Therefore there are no working parts, practically speaking, in contact with an erosive fluid. Again, there is no constant pulsation of the valve: it opens once for a single discharge. The lower

the air pressure required the higher the efficiency, as a smaller volume of air is required to raise a given volume of sewage.

CAPITAL COST.

Exclusive of land, the capital cost includes every expense that occurs under the five items mentioned above.

The advocates for installing pumps in place of ejectors, when both have equal claims, invariably put forward the plea of reduced capital outlay. Heretofore this claim was without doubt justified, but was almost entirely due to the absence of competition in manufacture, and the expense of economical compressing engines. At the present day this is by no means the case.

In this case both the installations briefly outlined are of great magnitude, and the cost of each exceeded £300,000, but there was a difference of only 15 per cent. in favour of the pumps. When a multiple ejector system discharges direct to the disposal works in place of a single-pump station, the greatly reduced cost of constructing shallow sewers must not be lost sight of.

In raising crude sewage it is not only the value of the work done that should be considered, but the way that work is done and the means employed to do it.

For instance, we might install a highly efficient plant, commercially, at a small capital cost; but it might perform its work in such a manner as to render the locality uninhabitable. The cost per given volume raised is of strictly relative value to other conditions being fulfilled and by no means the only factor to be decided, any more than the contractors' mechanical efficiency trial can be taken as a proof of economical working over a number of years under daily working conditions.

Maintenance.

It is often assumed that the most efficient device mechanically will be the most economical in upkeep and maintenance. It should be so, as the cost of fuel consumed to generate the motive power is usually the largest item in the balance sheet ; but it is by no means always the case. Pumps and ejectors for raising sewage are invariably in the hands of municipalities and corporations, and the cost of maintenance is usually accepted as an inevitable item of expense whatever it may be, regardless of the fact that in many cases by insisting on essentials being kept in the highest state of repair and suppressing the superfluous, economies of even 50 per cent. may be effected. But it requires an experienced engineer to do this with a free hand and a conscientious interest in the machinery under his care.

It is difficult to magnify the immense discrepancies that may exist between two power systems in the matter of running costs, or the extent to which secondary matters will be permitted to nullify the benefits of heavy capital expenditure.

Reports.

Whatever the installation may be, the commercial efficiency will largely depend on careful supervision and accurate records from which reports can be compiled, in order that one year may be compared with another and estimates made in advance of what will be required. It is often as wasteful to order too much in advance as it is false economy to cut down requirements that increase efficiency.

Reports should be brief and concise, and records of expenditure tabulated in their simplest form. They should commence with a paragraph stating the object

of the installation, at the same time giving a summary of the plant, together with its power and capacity, as with changes in administration it may be quite unknown to those to whom the report is submitted. The existing condition of the machinery, replacements required, quantity of stores consumed, and on hand, number of staff and their wages, with all suchlike information, should be given in detail.

If monthly reports have previously been made, no difficulty will be experienced in collecting such information, which in turn is compiled from a day book kept in the power house and filled in by the driver. This book should be divided into columns and record the number of the units in use, revolutions per minute made by the engine each shift, the weight of fuel consumed, steam pressure maintained, gauge pressure, and any unusual incidents.

Daily Discharge.

In a pumping installation the volume raised may be calculated from the revolutions of the engine, but provision should be made for checking the discharge periodically. Any serious falling off will be observed from the records, as the pump would either have to increase its speed or additional power would have to be employed to keep the sewage at the required level.

In the case of ejectors each one is provided with an automatic counter, and the strokes are recorded every two or three days, from which it is easy to calculate the discharge.

Taking one day with another, there is little variation in the discharge from sewers in the absence of rain; but the variation in the twenty-four hours is of great magnitude according to the time of day.

It is now proposed to give examples of the actual yearly maintenance costs of three methods of raising sewage—that is, by the reciprocating pump, the centrifugal pump, and the pneumatic ejector, all pumping from the same source. In every case these costs are much higher than exist in England; but that is of little consequence, as they are given for the sake of comparing one system with another under similar conditions of labour and maintenance.

In the first two tables the pumps are driven by electric motors, to which current was supplied at the rate of 2d. to 4d. a unit, an almost prohibitive figure. On the other hand, in the third table coal was supplied to the power house at £3, 6s. 2d. per ton, which is no less expensive in comparison.

Maintenance Tables: Pumps.

'A.' *Maintenance of* 12 *in.* × 12 *in. Reciprocating Pump*

STAFF

No.	Occupation.	Rate per month.			Rate per year.			Totals.		
		£	*s.*	*d.*	£	*s.*	*d.*			
1	Electrician .	12	6	8	148	0	0			
1	Mechanic .	9	4	6	110	14	0			
2	Greasers .	3	1	6	73	16	0			
1	Labourer .	2	2	6	25	10	0			
1	Watchman .	2	0	0	24	0	0	£382	0	0

Power, Stores, Repairs, etc.

	£	*s.*	*d.*			
Electric current power account	1263	6	8	1263	6	8
Lubricating oil . . .	7	3	2			
Waste, soap, polish, emery, cleaners, etc. . . .	15	0	0			
Hydraulic packing for pump ram	11	8	5			
Valve leather . . .	7	0	1			
Gauge glasses, paint, etc. .	3	9	0			
Incandescent lamps . .	0	15	0			
Disinfectant . . .	2	6	3			
Three cast-iron rams, less old rams as scrap brass . .	4	7	2	51	9	1
Current for lighting station .	18	2	6			
Fresh water . . .	21	3	7	39	6	1
				£1736	1	10

The volume of crude sewage discharged for this expenditure at 280 head=90,684,880 gallons.

Therefore the cost per 1000 gallons=4·59 pence.

'B.' *Maintenance of* 14-*in. Centrifugal Pump*

STAFF

No.	Occupation.	Rate per month. £	s.	d.	Rate per year. £	s.	d.	Totals. £	s.	d.
1	Electrician .	12	6	8	148	0	0			
1	Mechanic .	9	4	6	110	14	0			
2	Greasers .	3	1	6	73	16	0			
1	Labourer .	2	2	6	25	10	0			
1	Watchman .	2	0	0	24	0	0	£382	0	0
	POWER, STORES, REPAIRS, ETC.				£	s.	d.			
	Electric current power account				264	5	7	264	5	7
	Lubricating oil . . .				2	18	0			
	Cotton waste . . .				3	5	8			
	Paraffin				1	11	6			
	Grease				0	9	4			
	Soap, polish, and emery .				2	13	6			
	Floor cloth				0	15	0			
	Brushes				1	14	8			
	Hose and couplings . .				1	3	3			
	Insertion for joints . .				2	17	5			
	Flexible cable . . .				0	7	5			
	$1\frac{1}{2}$ W.I. piping . . .				1	14	3			
	Copper sheet . . .				0	12	0			
	Switch repairs . . .				0	13	3			
	Sundries				0	14	7	21	9	10
	Fresh-water supply . .				73	6	0			
	Current for lighting . .				12	0	0	85	6	0
								£753	1	5

The volume of crude sewage discharged for this expenditure at 8 ft. head=133,640,749 gallons.

Therefore the cost per 1000 gallons=1·35 pence.

Maintenance Costs of Reciprocating and Centrifugal Pumps.

Table 'A' shows the yearly expenses in running a three-throw 12 in. × 12 in. single-acting ram pump, driven by a 64 horse-power motor. Considering the great head and nature of the effluent which was heavily charged with cab-rank refuse and road grit, together with the high cost of the power, the rate is not excessive.

Table 'B' shows the yearly expense of running a 14-in. centrifugal pump drawing from the same sump. This pump was fixed below the level of the water in the sump, and was driven by a vertical shaft coupled to a 25 horse-power motor.

The wages of the staff are the same, but with only 8 ft. head the power consumed was much less. On the other hand, a constant supply of fresh water under pressure was required for the forced lubrication of the thrust bearing and impeller. Even then the impeller had to be withdrawn every few weeks, to clear fibrous matter and obstructions from the impeller ducts.

In neither of these tables has the interest on capital cost been allowed for; but the Electric Light Company's profit is included in the cost of the power.

The capital cost of the ram pump is of course higher, as would be expected with the greater power. On the other hand, no deep underground chamber is required in which to erect the pump, and there would be little difference in the total cost including buildings. Both plants were run with twelve-hour shifts, but eight hours is to be recommended.

Maintenance Tables: Ejectors.

'C.' *Maintenance, Ejector System*

STAFF

No.	Occupation.	Rate per month.			Rate per year.			Totals.		
		£	s.	d.	£	s.	d.	£	s.	d.
3	Drivers . .	8	3	6	294	6	0			
3	Firemen .	3	4	7	116	5	0			
6	Greasers .	3	1	5	221	3	0			
2	Greasers .	2	3	7	52	6	0			
2	Fitters . .	3	15	0	90	0	0			
6	Labourers .	1	17	5	134	8	0			
2	Trimmers .	1	17	5	44	18	0	953	6	0
1	Electrician .	14	5	6	171	7	0			
1	Wireman .	2	10	0	27	0	0			
4	Watchmen .	2	2	7	102	4	0	300	11	0
1	Mechanic .	9	4	6	110	14	0			
2	Inspectors .	3	1	5	73	14	0			
2	Labourers .	1	17	5	42	18	0			
2	Boys . .	1	11	2	38	8	0	265	14	0
	Casual labour		..		141	0	0	141	0	0
								£1660	11	0

'D.' *Maintenance, Ejector System*

Stores, Repairs, etc.	£ s. d.	£ s. d.
Coal, 200 tons at £2, 4s. 2d. per ton	441 13 4	
Coal, 1069 tons at £3, 6s. 2d. per ton	3536 12 2	3978 5 6
Cylinder oil	92 1 3	
Journal oil	75 2 0	
Crank chamber oil . .	29 12 5	
Diesel oil	9 3 7	
Cotton waste	79 9 6	
Rags (cleaning)	4 19 5	
Grease and tallow . .	7 9 7	
Soft soap, soda, polish, etc. .	51 18 5	349 16 2
Brooms, brushes, cloths .	13 2 0	
Oil trays, valve springs .	15 17 6	
Electric lamps, wire, etc. .	13 19 1	
Gauge glasses and fittings .	11 16 1	
Twist drills, saw blades .	13 11 6	
Fire bricks and fire clay .	7 8 9	
Files, washers, tool steel .	10 11 2	
Asbestos and hemp packing	41 0 3	
Drugs and distemper .	6 7 0	
W.I. piping, unions, and fittings	22 18 3	
Pig lead, firewood, and yarn	24 15 9	181 7 4
Repairs to machinery . .	59 17 6	
Roads and buildings repairs	193 15 0	
Paint, composition, etc. .	118 15 0	
Sundries	95 17 8	
Ejector spares	35 4 6	503 9 8
Venturi meter flushing water	49 6 10	
Power-house water supply .	489 11 7	
Garden water, unfiltered .	26 11 2	565 9 7
		£5578 8 3
Wages of staff . .	1660 11 0	1660 11 0
		£7238 19 3

The volume of crude sewage discharged for this expenditure at 50 ft. head=884,126,980 gallons.

Therefore the cost per 1000 gallons=1·96 pence.

Maintenance Costs of Ejector System.

Tables 'C' and 'D' show the maintenance costs for one year of an ejector system. Of 63 ejector stations, 36 were in daily use. These figures include 52 miles of pressure mains besides the power house.

It will be observed from the list 'C' giving the staff that most of the labour is absorbed by the power house. Examination of the various items on list 'D' shows there has been no attempt at economy and, with the exception of labour which is cheap, that rates are much in advance of those in England. Some items, such as repairs to roads and buildings, include details that should be credited to other sections, and the large figures for water supply were of a purely temporary character, owing to its being necessary to draw water for condensing purposes from the city mains pending the construction of the necessary works for the station's permanent supply. The object of giving these details is not, as before stated, in order to claim or demonstrate how economically or extravagantly crude sewage can be raised, but solely for the purpose of comparing one system with another under the same conditions of supervision and pumping the same effluent. Herein lies the value of the figures given.

To compare a ram pump in England with a centrifugal pump in India and an ejector system in Spain, is of little value if we wish to arrive at figures for the purpose of comparison. For the same reason interest on capital is not given, as land and buildings should be included, and there is no object in comparing such values.

MAINTENANCE: DIFFICULTIES OF COMPARISON.

Explicit information from a variety of sources is difficult to obtain, and it is still more difficult to draw up a table of fair comparisons between running plants. Local circumstances and conditions prohibit the various items of expenditure from being tabulated on the same basis. In one locality fuel will be expensive and labour cheap. Cheap labour is invariably inefficient, and what is saved in this respect is taken out in repairs.

Again, corporations and municipalities often derive their power for lifting sewage from rubbish destructors, and in such cases the costs of the power would be lower, whether pumps or ejectors were utilised. On the other hand, unless very precise details and records were kept it would be difficult to decide to what extent the transport and handling of such rubbish should be debited to the cost of raising the sewage.

Other matters of controversy could be suggested, and those who are familiar with the subject will appreciate the fact that unless the conditions of supervision, labour, stores, fuel are the same, besides raising the same effluent as in these examples, misleading conclusions may be arrived at.

Much depends on the knowledge and interests of the responsible authorities and supervising staff. The idea that an economical plant will remain economical without unremitting attention, no matter of what type it may be, is a fallacy; but it can be stated with confidence that the simplest machinery is the cheapest to run. The locality which enables the whole of the effluent to be raised by a single-power engine, whether pump or ejector, will have a great advantage in costs over a sectional system.

In comparing expenses the magnitude of the power, total volume and head of water must be borne in mind, as the greater the volume the cheaper it is to lift per 1000 gallons.

Maintenance consists of supervision, fuel, repairs, and consumable stores.

'E.' *Commercial Efficiency: Table of Pumps and Ejectors*

COST OF RAISING CRUDE SEWAGE

Ref.	Type of Engine.	Head.	Cost in pence. Per 1000 gallons.	Cost in pence. Per 100 ft. head per 1000 gallons.	Per year. Volume, gallons.
A	Reciprocating pump .	290 ft.	4·475	1·543	86,169,373
B	Centrifugal pump .	8 „	1·421	17·762	141,757,973
C	Ejectors (72)	50 „	1·466	2·940	884,596,791
D	Reciprocating pump .	117 „	1·364	1·166	1,111,250,314
E	Ejectors (39)	44 „	0·625	1·420	. .
F	Ejectors .	65 „	1·410	2·169	790,000,000
G	Ejectors .	40 „	2·000	5·000	273,750,000

In the last column but one the cost per 1000 gallons per 100 ft. head is given in the above table, as the author is well aware that it is usually considered a recognised standard of comparison; but it is submitted that in practice it is of purely academic value, as it is obvious if we only require to raise the effluent 50 feet, it is quite immaterial if the apparatus installed is inefficient and costly when called upon to raise sewage 100 feet.

It is clear that the commercial efficiency of the ejector is not far short of the reciprocating pump, and the centrifugal pump falls short of both. When it is remembered that the steam consumed per indicated horse-power per hour for 'D' is only 9·75 lbs. in place of 15·32 lbs. per hour for 'C,' it is obvious that if the ejector system was actuated by such an economical steam engine, there would be little to chose between the two systems.

'A,' 'B,' 'C,' 'D' are all raising the same effluent heavily charged with grit and refuse. 'A,' 'B' are driven by electric motors for which the current is purchased and therefore includes a commercial profit.

In comparison with 'D,' 'A' has the advantage of a high piston speed and multiple clear-way valves, whereas 'D' has a low piston speed and large rectangular valves. The trial results of 'D' are shown on page 66, and 'A' is the 12 in. × 12 in. pump on the diagram, Plate XI.

The poor result and high cost (if the 8-ft. head is taken into consideration) of the centrifugal pump is due to slip and loss of velocity, and though the cost of pumping with the 6-in. centrifugal pump on Plate XI. could not be ascertained, it would hardly have made a better showing.

The first four pumps in Table 'E' are employed on the Cairo main drainage. *E* is the ejector system at Gosport, England, and without doubt gives a most economical result. *F* is the Karachi system, India, and *G* the Southampton system, England. The author is indebted to the Chief Engineers of Gosport, Karachi, and Southampton for the figures for these places.

Individual instances could no doubt be given that would apparently refute these figures and show that both the reciprocating pump and the centrifugal pump will raise sewage at a much lower rate per 1000 gallons,

but it would probably be found that more favourable circumstances existed.

For instance, an installation of centrifugal pumps driven by internal-combustion engines, dealing with diluted sewage and storm water in large quantities, would show a greatly reduced figure, even allowing for replacing the whole of the pumps after a few years ; but it must be distinctly understood that this table does not refer to such conditions, but the raising of crude sewage as herein defined, that is, an effluent discharged by city sewers, containing every conceivable substance that may cause obstruction or destruction to mechanical parts.

CHAPTER V

STAFF: SUPERVISING

In large cities the drainage staff will only be a section of the public service. In urban districts the Borough Engineers will probably have full direction of such works.

Let us assume the installations to be constructed and supervised are of such magnitude as those described in the last chapter.

There will be a chief engineer and his assistants for drawing up designs, specifications and estimates, and examining tenders; a resident engineer and his staff of inspectors for supervising the construction and making out contractors' monthly certificates for payment; and eventually a running staff, which will be organised as the works are completed. In drainage schemes the constructional work may still be in progress after the running staff have commenced their duties, especially in an ejector system, as one of its principal merits consists of being able to lay down new ejector areas as required, instead of having to complete the whole system in a single contract. By this means the machinery is brought into use as soon as it is put down and does not have to remain rusting in the ground as buried capital.

Every man on the staff cannot be an experienced engineer, but for economical construction it is absolutely necessary that at least half the number employed should have had a sound practical training in the particular

class of work they are called upon to supervise: especially those who have to decide technical questions and deal with contractors.

Paper qualifications are excellent things, but too much reliance should not be placed upon them, and it is the height of foolishness to rule out an otherwise able man because he does not possess certain degrees or academic distinction. It need scarcely be remarked that appointments by influence on a technical staff can only result in waste, extravagance, and friction. In selecting officers for technical posts we want to know exactly what their experience has been. If they possess academic degrees, so much the better, but we must know how they were obtained and what they were for.

For instance, an academic honour bestowed on a student for a treatise on the theory of the gas engine is of no economic advantage in drawing up a specification for a pneumatic ejector system. In the same way, the construction of weirs and sea walls is not an efficient training ground for the supervision of a tramway power station.

Of all the various branches of engineering there is less information concerning drainage work to be derived from text-books and theory than in any other. Such work cannot be standardised except in mechanical detail. Each scheme has to be considered on its merits, and the wider the experience of the responsible engineer, the better he is able to adapt available means to suit his purpose.

This is not the place to enter into the merits and failings of the training of the average engineer in the public service; but it may be said that if he is to occupy a responsible post, with credit to himself, his work, and his employers, the average academic course, the pupilage in

the office, the superficial 'works training,' the appointment as 'assistant' to the Borough Engineer, the 'automatic promotion' is rarely sufficient.

One half of his profession remains a closed book to him. Efficiency to him is an academic expression. There is nothing so conducive to the development of character as having to earn a living on the training you have had. There is nothing so chastening to youthful conceit as seeking employment on your merits, or so injurious to initiation and resource as being provided with a comfortable post without the smallest exertion or disappointment. The consulting engineer's office will not do. The public service will not do. They require or should require qualified men to design, administrate, and supervise constructional or maintenance work, and to perform such functions with credit the engineer must know from precedent how the work should be done. He must have obtained employment which will have given him an insight into the great realities of time, labour, and expenditure, that is to say, he must have gained experience in the fierce competitive market of industrial enterprise, which is the constant spur to efficiency and improvement. It is this, before all else, that will produce the man who knows precisely what to do and how to do it in after years. To march about a job in progress without knowing the why and wherefore of what he sees is a totally different thing to having been employed upon the work himself.

He cannot guess the contractor's point of view if he has not worked for him. There is the seller's point of view and the buyer's point of view to every pound sterling worth of work that is carried out.

There are intricate questions, apart from the actual work, that must be considered. For instance, there is

the time and labour that it takes to perform a certain task, administration, organisation and procedure, and the inevitable contingencies which cannot be specified in a contract. If he is ignorant of such matters when he comes to hold a responsible position, his brain is bankrupt of initiative and destitute of resource in those difficulties which occur in every large enterprise. He will be an utter stranger to those small considerations to a staff which mean so much and cost so little, but promote harmony and efficiency and enable us to distinguish between what is a necessity and what is superfluous. He must know his men and what they can do. If he does not know the road himself he cannot point it out to others. And, finally, it is the only school in which he can learn to direct with confidence, argue with force, protect his own and his employer's interests from commercial abuses, and avoid being reduced to impotence or being constantly imposed upon when his turn comes to hold high office in the public services.

There is no such thing as a man who is born with experience.

However, as it is the efficiency of the machinery and its maintenance that is under discussion, we will now compare the staff of a pumping station with that of an ejector system.

There is a popular notion that the ejector system requires a much larger staff to keep it in order, but this is not really the case.

Pumping-station Staff.

The following table gives some idea of the essential men required for routine work, allowing for three eight hour shifts. In England it is sometimes the practice to run with only two shifts, but this cannot be recommended.

ESSENTIAL ROUTINE MEN FOR PUMPING STATION

Superintendent
Assistant
Mechanic
Mechanic
Electrician

Driver	Driver	Driver
Fireman	Fireman	Fireman
Trimmer	Trimmer	Trimmer
Cleaner	Cleaner	Cleaner
Cleaner	Cleaner	Cleaner
Cleaner	Cleaner	Cleaner

Screening Chamber

Cleaner	Cleaner	Cleaner
Labourer	Labourer	Labourer
Labourer	Labourer	Labourer
Labourer	Labourer	Labourer

To this list should be added mechanics' assistants, a clerk, storekeeper, telephone lad, and three or four men for cleaning the buildings, say forty-four in all.

EJECTOR-SYSTEM STAFF.

The following table gives some idea of the essential men required for routine work. The wages paid to such men will be seen on pages 84 and 86, but in England the scale would be considerably higher.

ESSENTIAL ROUTINE MEN FOR EJECTOR SYSTEM

Superintendent
Assistant
Mechanic
Mechanic

Driver	Driver	Driver
Fireman	Fireman	Fireman
Trimmer	Trimmer	Trimmer
Cleaner	Cleaner	Cleaner
Cleaner	Cleaner	Cleaner

Ejectors

Inspector	Inspector	Inspector	Inspector	Inspector
Assistant	Assistant	Assistant	Assistant	Assistant
Labourer	Labourer	Labourer	Labourer	Labourer

Allowing the same number of assistants, etc., this makes a total of forty-three in all.

As a rule it will be found that extra hands and casual labour omitted in both these lists will, during the year, amount to more for the pumping station than for the ejector system. Large pumps require at least an extra cleaner compared to compressors, and though there is no outside staff, the screening chamber absorbs a lot of labour both in actual attendance and repairs. Again, in both these cases the water-tube boilers are oil-fired: with coal, more firemen and trimmers are required. The expense of handling oil fuel from the railway to the furnace is very much less than the expense of handling coal, especially if it has to be carted. Provided the air-compressing machinery is of simple construction, two power units of 150 horse-power each can be kept running by the above staff.

There is little work on air-compressing machinery compared to that on large pumps, and the mechanic will find time to replace the leathers on the ejector valves and assist in testing the air mains. On the other hand, air-compressing machinery, with complicated gear, will provide a great deal of work to keep it in an efficient state.

Ejector Inspectors' Duties.

Each of the inspectors would be responsible for twelve ejector stations, ten miles of pressure mains, with an aggregate of 280 valves, about half of which would be on the ejectors. They record the counter readings, inspect the flap valves, fit the cup leathers, and see that all is in order. It is also their business to know the position of every yard of main and valve in their section and periodically test every length for leakage. The labourers would work together, excavating joints if not required on the ejector, and must be always prepared for any break-down work. On large systems embracing many square miles a light motor lorry is of the greatest value in picking up both men and material for any repair work in progress.

Time spent on the organisation and supervision of the working staff is never wasted. In a pumping installation the men work under the eye of the engineer in charge. In the ejector system they do not. By the true beat of the valves and the pressure gauge the engineer can himself detect leakage or faulty running of his pumps, but he must depend upon the accurate information of his inspectors for his knowledge of the ejector.

Quarters for Staff.

The provision of a house on the station grounds is part of the superintendent's salary. If there is no lodging, allowance is granted and he takes up his quarters as close to the station as he can.

It is of even more importance to provide quarters for an ejector system than for a pumping station. In addition to the house for the superintendent, the drivers, firemen, and ejector inspectors require accommodation.

Every engineer experienced in his profession knows that provision must be made for strikes, sickness, and emergency, and the more of his staff he is able to provide with quarters close to the station, the less he has to fear breakdown from such causes. Again, if the ejector inspectors live two or three miles from the power station, and their particular section is close to their homes, it is obvious they would simply waste time by making a double journey to and from the power house each day to report. If they do not personally report, the superintendent will be out of touch with these men for weeks at a time, and have no check on their work.

Inspection of Ejectors.

Opinions differ as to how often inspection is necessary. Provided the ejector is in good condition, it will run for many months ; but to leave them for such long periods unattended cannot be recommended, if efficiency is desired. If the ejector stations are working at their full capacity, and stoppage for even a few hours would cause flooding of basements, they should be examined once a day, especially in certain countries where labour is cheap but inefficient, and a 'blow through' may occur from some neglect. In England twice a week should be enough.

Selection of Staff.

With regard to a pumping installation of rotary crank and flywheel engines, there is not much difficulty in obtaining the services of a suitable engineer-in-charge as superintendent. Men with marine experience often fill such situations with credit. They are accustomed to exercising authority, and in most cases are competent instructors, besides being able to test their own engines.

The staff will respect them, discipline will be maintained, and any casual visitor to the station will notice that though the place is spotlessly clean, the superintendent 'appears' to have little to do!

There is no surer sign of efficiency than the self-running appearance of a power station.

Such men will be in possession of a Board of Trade certificate, and able to return to sea if they so desire. An engineer in charge has very often to be insistent on money being granted for certain purposes, and an adequate remuneration for the staff, and unless he is in a more or less independent position he may have to put up with parsimony and inefficiency on every hand.

The selection of an ejector staff, from superintendent to inspector, is not an easy matter. In the first place, the engineer must have a complete knowledge of the ejectors.

He must be able to visualise every working part, so that when an inspector reports a fault he will be able to instruct him precisely what to do to prevent its recurring, as it will be quite impossible for him to visit every ejector station himself.

He must have tact and patience, encourage the reporting of any fault or peculiarity in working, or he will never be informed of those very details he ought to know. If once the inspecting staff are reprimanded and fined for reporting faults, he will never obtain the best results from his men.

The inconstant human factor is the most potent influence we have to deal with, therefore we must understand the class of man who actually supervises the work. If you do not gain their confidence, you cannot expect them to have confidence in you. You can standardise the parts of an intricate machine, but you cannot standardise the human intellect.

The best plan is to select reliable lads of seventeen or eighteen years of age, and explain the working of the ejectors to them. If, after a few months they show intelligence in their routine work, and take an interest in the records, place them on the staff, and draw up a scale of pay advancing each year, till it arrives at the figure paid to mechanics. At the same time inform them they will be entitled to lodging and the usual privileges. If he is a good man give him inducements to make it his permanent work. It will repay you many times over, as on these men the real efficiency of the scheme will depend.

The work required is little more than *care with intelligence.* If a skilled mechanic is engaged for routine work of this description, he will look down on it in a few months, and resign. Constant changes will mean endless explaining and reinstructing new hands, as it is quite the exception to pick up men who have already had experience in the work.

Apart from mere chance, the ability to select the right man for a particular post depends entirely on the experience and disposition of those whose duty it is to discriminate between the applicants.

A competent man will select competent assistants, while the incompetent invariably consider their own shortcomings and desires before the work to be done. Talent is not wanted where it is not understood.

Faculties of observation and record are the surest signs of competency.

Be just, encourage ability, and judge your men by the work they do. Bear in mind the labourer is worthy of his hire. Pay a good wage to a good man; cheap labour is by far the most extravagant of all 'economies' in the long run. You cannot drive a man with brains; but

you can lead him anywhere. Consider the interests of those you employ, and never trade on their privileges. If they are entitled to a day off, see that they get it. Be large-minded before all else, eschew meanness, and do not lower yourself by blaming your subordinates for your own ignorance. Never chide them or abuse them before others, or condemn an action in haste. He may be right and you may be wrong, and two wrongs do not make a right. You cannot expect them to stand by you if you do not stand by them when the critical times come. There is nothing more terrible than ignorance with spurs on. Loyalty of a staff is won; it cannot be made to order.

Never make a practice of disparaging your men or discrediting their work; it earns nothing but contempt. Unless you have served your time, and done the work they are doing, and know for example, from daily experience, why a flat file has a safe edge, and a twist drill a taper shank, depend upon it they can give you points. Even a navvy has a method in using his pick and shovel.

Do not forget that endurance and adversity have a limit.

Avoid giving humilating slights; there is nothing so disastrous to your own dignity and prestige. No system, however imperfect and unjust, compels non-recognition and obstinate indifference to merit. Freeze merit out of existence and the cogs of the administrative machine rapidly deteriorate and rust. No system is perfect, but administration is the soul of every system, and the responsibility of a discontented service, which is the basis of waste and inefficiency, cannot be evaded by those who are entrusted with administrative powers.

If you do not pay a good man a good wage, sooner or later you will lose him.

If your men have the chance of promotion to a better job, assist them all you can; you will be surprised how many good men you have on your staff.

If some particular work has to be done in a hurry, ask them if they have got all they want to do it. If they have not, see that they get it, and work will be done in record time.

If you do not pay your men sufficient wages to live on, you cannot expect them to devote the whole of their time to your service.

You want the men who are thinking how well they can do the work, and not how they can hang on to their job.

Every post is worth a certain sum, plus a margin for ability and responsibility. To fill a good post with a cheap man simply lowers the standard of work. If men are increased in pay solely for length of service, all must be treated alike. Partiality in the wages sheet is the cause of more discontent and friction than any other cause.

The author has supervised labour of many nationalities, in many countries, from marine engineers and skilled European mechanics to African natives and Arab convicts, and human nature is much the same all the world over. Eastern races, though illiterate, are quick to sum up the character and disposition of their superiors. They appreciate justice no less than the best European mechanic appreciates knowledge and ability; and there is nothing so conducive to respect and discipline as for the engineer in charge to be a man of action, who knows precisely what to do and how to do it.

Impossible orders will ruin the best of men, and obstinate

indifference rapidly breeds contempt. No matter what the work is, 'costs and efficiency' are as much dependent, if not more so, on the working of the staff as on the most economical machinery. An inefficient staff, with indifferent supervision, will be responsible for wasted stores, bad repairs, constant friction, and a hundred and one petty troubles which only those who have had experience can realise.

CHAPTER VI

SINKING AND ERECTION OF CAST-IRON TUBBINGS

Cast-iron Tubbing.

Ejectors may be placed in cast-iron tubbings or masonry chambers. For many reasons the cast-iron tubbing is to be preferred in water-logged ground. They can be sunk with compressed air by means of the air lock, after the manner of a bridge caisson. There is better control of the sinking of the chamber, and less chance of danger to surrounding property from ground subsidence. The lead joints between the tubbing segments can be caulked and recaulked absolutely tight, even after settlement, and such chambers can be sunk beneath the streets in restricted areas, with a minimum of excavation. Presumably the masonry chamber has a longer life, but cast-iron water-pipes have been in use for upwards of a century, and as far as the author is aware, no time limit has been determined for the life of a cast-iron tubbing under average conditions.

Plate VIII., page 26, shows a typical example of a cast-iron tubbing, sunk in water-logged ground in a comparatively narrow street. The tubbing consists of cast-iron segments, which are flanged and bolted together, thus making a series of rings, which are built up one upon the other, till the shell is completed.

The flanges are tapered and have a beading cast upon

one edge; thus when two flanges are drawn together there is a recess, into which is caulked a flattened lead-pipe, through which yarn has previously been threaded.

MARKING OUT TUBBING.

The first step in the sinking of the tubbing is to mark out the exact position in relation to the proposed street manhole, from which the effluent will gravitate to the ejectors.

Iron pegs are driven into the ground, or other suitable marks made at a distance from the actual site, so that lines can be run across the excavation for setting out the first ring, and checking the work as it proceeds. The position of these pegs or marks must be accurately noted, or much difficulty may be experienced later on, when it is desired to sink the manhole precisely in line with the inlet pipe to the ejector. A bench mark must also be made on the curb or other suitable spot, the value determined, and the level of the ground taken, in order that the entrance cover may be eventually set to correspond with the street macadam or pavement.

SINKING TUBBINGS.

A square excavation of such dimensions as to leave room for timbering, in addition to the outside diameter of the tubbing, is now carried down to water level. In this excavation the first ring is assembled and carefully lined up in position.

This ring is provided with a cutting edge, and on the inside of each segment are cast the flanges to which the floor is bolted after the tubbing has been sunk to its correct level. Each segment has its correct place, and great care must be taken in erecting the first ring that the upper segment through which the inlet pipe passes

will come into its correct position, in line with the manhole peg, as the tubbing cannot be turned when erected. The inspector under whose supervision the work is being carried out must carefully inspect the plates for cracks, as they are not infrequently fractured in transport and the crack only disclosed under water pressure, when the tubbing is completed. To remove a lower segment when the work is finished is both a tedious and expensive business.

By means of a hand crane successive rings are now added to the one already in position, till the level of the cone is reached. The floor segments and steel joists are now lowered into the shell, as they will not pass through the air lock, and either rest on temporary girders or are suspended by chains and shackles to the flanges of the segments.

The delivery main passes through one of the cone segments, which ring is next fixed in place, on which again rest the neck rings one above the other. The upper neck ring is provided with bosses for the air main and exhaust pipe connections, and they must face in the right direction, as shown on the site plan. Finally the cover is bolted on, to which the air lock is attached.

Air Lock for Sinking Tubbing.

The air lock consists of two wrought-iron cylindrical chambers, with dished ends, bolted to one another so as to form twin compartments. In one end of one compartment is a circular outlet, to which is riveted a flange for bolting to the tubbing cover. This forms the base or foot of the air lock. On the opposite end or top are flanges for the relief valve and pressure gauge. In one side of this chamber is a rectangular opening to correspond with a similar opening in the twin compartment,

which is also provided with a second rectangular opening to the atmosphere. Heavy doors are hinged to these openings, and the two compartments are of such dimensions that two men can stand together in either of the two chambers when the partition door is closed. Assuming a man desires to enter the tubbing under pressure, he climbs into the air lock and closes the door after him. He then opens a pet cock in the partition door, and permits the air pressure from the tubbing to fill the air lock till an equilibrium has been established. He then opens the partition door, closes it after him, and descends through the base of this chamber by means of a rope ladder to the bottom of the tubbing. The air lock is now under pressure, and before a second man can enter from the atmosphere, he must relieve the pressure by opening the pet cock to the atmosphere in precisely the same way as the first man admitted the compressed air from the tubbing to the air lock.

Sinking under Pressure.

To sink the tubbing, the soil is excavated from the bottom and hoisted up through the air lock, the air pressure being sufficient to prevent any water from entering the tubbing. When 2 ft. or 3 ft. have been excavated, the air pressure is lowered and the tubbing sinks. Once this operation is started, work continues night and day, as it is of importance that the air pressure should not be removed till the floor is fixed, or the sand and water will rise up in the tubbing and an immense amount of re-excavation will have to be carried out.

The position of the tubbing is determined from time to time with the level and staff, the length of the cast-iron plates from the cover to the invert of the aperture for the inlet pipe having been previously ascertained.

While the tubbing is being sunk this aperture is covered with a blank flange. By keeping the staff on the cover, and looking through the level while the tubbing is sinking and regulating the air-relief valve, the invert of the inlet can be brought to rest exactly at the predetermined level.

To ease the process of sinking, it is a good plan to fill in the space between the timbering and the tubbing walls with gravel to a depth of 2 ft. or 3 ft. before sinking commences. This acts as a lubricant, and there is not so much tendency for the tubbing to 'drag' the surrounding soil with it and cause local subsidence.

During the initial stages of sinking, the tubbing must be weighted or the air pressure is liable to lift the whole shell, with the result that the air will blow out from under the cutting edge, and the tubbing, which is top heavy with the air lock in position, will cant over, and be very difficult to right. With a 20-ft. tubbing even a pressure of a few pounds must be applied with care. As the cone sinks the earth is filled in and the weights are removed.

Whether the tubbing is sunk with compressed air or by hand excavation and steam pumps, great care must be exercised to see that the filling takes place before the floor is caulked and made water-tight, as the chamber is buoyant and will float up, which will cause a heavy inrush of sand beneath the floor plates and undermine the nearest house foundations.

Provided the tubbing maintains a vertical position during sinking, and only has to withstand an even pressure, there is ample strength; but it is easy to fracture the plates if the shell is squeezed unequally, or great pressure is brought to bear locally in attempting to right a tubbing that has canted over. At this stage the principal trouble is the tendency of the tubbing to sink too

far into the sand. If the air pressure is released by accident from the bursting of a pipe or a joint failing, the shell will sink 4 ft. or 5 ft., and there is no means of stopping it. At the same time the sand will rise up from the bottom, and the whole interior have to be re-excavated. The tubbing can be raised by air pressure and hydraulic jacks ; but it is a delicate and tedious business, as sufficient air pressure for this purpose is invariably sufficient to start a bad ‘ blow through ’ in soft, water-logged soil.

Through sandy soil or fine gravel the tubbing sinks very easily, but when stiff clay beds are met with, it is often necessary to make a special platform to rest on the lugs cast on the outside of the cone for the purpose, and pile it high with scores of sandbags. If the clay bed is dry and hard, and only becomes wet round the tubbing from the subsoil water forcing its way up, the shell will be held in a vice-like grip, and will not sink without external excavation.

Tubbing Floor, Fixing in Place.

With the sinking of the shell to the required depth, the next operation is to fix the floor, still under air pressure. The segments are lowered on to the sand, assembled together, and drawn up to the flanges provided for the purpose on the bottom ring. Care must be taken that the flanges of these floor segments are drawn evenly together, or unequal strains are liable to be set up, which will cause fracture when the equilibrium between the internal air pressure and the subsoil water is destroyed by removing the air lock.

In this class of tubbing the flanges of the segments are not machined, and it will readily be understood that, owing to the lead joints, the whole tubbing is more or less flexible, and depends upon its rigidity for the external

pressure. When the internal pressure is removed settlement of the plates will occur, as the whole cylinder is subject to external pressure alone. The strength of a circular shell, under an even external pressure, is well known, but with local strains flanges are easily fractured. The floor should remain perfectly water-tight after the air lock has been removed for twenty-four hours (that is to say, under atmospheric pressure), with bolts tightened up, joints caulked, and steel joists firmly wedged in position, as the subsoil takes some hours before it exerts its full pressure. This is probably due to the compressed air forcing the water through the sand—that is to say, the soil is comparatively dry round the tubbing while the sinking is in progress under air pressure.

It must always be borne in mind that the floor is under great pressure, and it is by no means infrequent for a rib or flange to split if the metal is not perfectly sound. With a cracked segment there is nothing for it but to replace it. Finally, the floor is filled with concrete rendered over in such a way as to drain to a small sump left in the concrete, and the tubbing is ready for the ejectors.

Setting Ejectors in Position.

There is no necessity to bolt the ejectors to the floor. They must be set level, and the base packed up till the inlet pipe and the delivery pipe come in line with their respective apertures in the walls of the tubbing, when they are grouted up. The internal bell weight must hang truly in place, and the bracket supporting the external lever fulcrum adjusted to such a position that the bell-rod passes freely through the crown of the ejector without any tendency to seize.

When red lead is used for jointing the cover, it should not be permitted to squeeze out of the joint, as it will harden and foul the top bell float. In some types of ejectors there is very little clearance. All rods, washers, nuts, etc., in contact with the fluid must, without exception, be of gun metal. The point to remember is that the action of the bell-rod must be perfectly free with a minimum of friction.

When the ejectors have been put together they should be filled with water, and at least the working air pressure applied, to ascertain if all the joints are tight. No leakage whatever should be permitted, and if air comes from the exhaust outlet, when the air valves are open, the exhaust valves should be refaced. Needless to say, the exhaust stop valves must be wide open when testing.

Ejector Inlet Pipe.

In Plate VIII., page 26, it will be noticed the inlet pipe passes through the wall of the tubbing. A better arrangement is for the ejector pipe to terminate in a spigot, leaded into a socket and flange, and this flange will bolt on to a boss on the inside of the tubbing. A boss sunk into the segment on the outside will enable the pipe from the tubbing to the inlet manhole to be entirely separate. The exterior boss must in no way stand out from the tubbing or it will impede sinking. If much settlement occurs when the inlet passes through the tubbing, it is liable to snap off, and can only be replaced at much expense.

Tubbing Sinking by Pump or Grab.

If no buildings are near the proposed site of a tubbing, and the soil is fairly stiff, it is cheaper and quicker to sink by hand excavation and a steam pump, as the men

can work in daylight and are not hampered by the air lock in getting rid of the spoil.

A third way is to excavate with a steam grab, and not pump out the water till it is desired to fix the floor, but in this method any stone or obstruction under the cutting edge of the bottom ring will cause the tubbing to cant over and sink unevenly. There is no economy in this method over the steam pump.

Brick Chambers.

In the case of circular brick chambers, they must either be built up from the bottom or sunk like a well by excavating the interior soil and building the masonry on the top, while the water is kept down by pumping. But the great objection to the use of steam pumps is the heavy subsidence of the surrounding ground which invariably takes place. If divers can be obtained to work in the depth of water that exists, no pumping is required, and the floor is made by filling the bottom with concrete, and finally grouting with liquid cement distributed by vertical pipes, previously fixed for the purpose.

Such chambers must be of substantial construction, and the crown may be corbelled in or arched over; but they cannot be guaranteed water-tight in the sense of having a perfectly dry internal surface on which neither seepage nor moisture can be detected; but if carefully built with the best materials will answer their purpose in certain situations. The only method of making a brick chamber of this description perfectly water-tight is by lining it with bitumen, with an internal lay of masonry. But it is necessary to lay the material on a dry surface. If it is laid on a cement surface under constant seepage the pressure will force it off.

Testing Tubbings and Brick Chambers.

It is not proposed to go into the matter of specifications, but it may be said the contractor should be held responsible for handing over the tubbing and ejectors complete in every detail, in a perfectly water-tight condition, as specified and described, and the test to which these chambers should be subjected is their ability to withstand the pressure of the subsoil water for one year without leakage. Some settlement may take place as subsoil water invariably differs in level according to the season of the year. It is not unusual to retain a small percentage of the contractor's price till the conditions have been fulfilled.

Air Compressed for Sinking Tubbings.

From 10 lb. to 12 lb. air pressure will be found sufficient for ordinary street work ; but when ejector tubbings are sunk 60 ft. and 70 ft. for draining the sludge from sewage sumps, a greater pressure is required. When the air pressure is first applied, it will be found that it takes a higher pressure to expel the water than it does to keep it from flowing into the tubbing.

Portable steam air-compressors are to be preferred for air-lock work; they are the most reliable, will run at a slow speed, and do not cause pulsations in the chamber, which react on the ear-drums with unpleasant effect. Again small internal-combustion engines can hardly be relied upon to run for three or four weeks continuously.

On the other hand, there is little room in narrow streets for operating such machinery, as it will consist of a horizontal flywheel, tandem compressing engine, mounted on a four-wheeled carriage, with another carriage for a 10 horse-power steam boiler, with its

coal and water receptacles. It is also expensive, and unless more than one portable unit is provided, only one tubbing can be sunk at a time.

There is, however, no reason why the permanent air main should not be laid first and a temporary stationary compressor plant put down by the contractor, so that several tubbings can be sunk at once, and the transportation of machinery about the city is done away with.

CHAPTER VII

EJECTOR AND AIR-MAIN FAULTS AND REMEDIES

As previously remarked, the pneumatic ejector is, comparatively speaking, an obscure apparatus compared to a pump. There are a few records of its merits, but none of its failings, and no reference work to which the Borough Engineer can turn for information on its daily working or when he has to consider the drainage of a new area, or remodel an existing system. Manufacturers' catalogues and special articles in the technical Press naturally confine their remarks and descriptions to the merits of the apparatus they wish to sell, and those simple precautions in erection, supervision, and maintenance, which make all the difference between satisfaction and disappointment, are not disclosed. Indeed, in nine cases out of ten, the designer and manufacturer are not aware of their existence.

What is understood is invariably selected in place of what is not understood, and ejectors have often been 'turned down' in preference to a pump for the sole reason that unknown difficulties which the ordinary pump attendant may not be able to correct, might jeopardise the success of the scheme. The very simplicity of the apparatus arouses suspicion, as if the ejector stops, there is often nothing to indicate the reason, and the attendant must know how to locate the cause without dismantling the whole machinery.

Sometimes it is easier to express the merits of a system by pointing out the failings to which it is subject. The engineer is then in a position to draw his own conclusions as to whether such failings are of such a nature as to counterbalance the obvious advantages. There is more to be learnt from careful records of what to avoid than from an able summary of an apparatus in perfect working order. It is for this reason that it is now proposed to describe some of the faults and failings of ejectors, air mains, and their accessories, together with those precautions which should be taken to avoid subsequent expense.

Causes of Ejectors Stopping.

There is no limit, practically speaking, as to how long an ejector will go on working.

The leathers of the inlet and discharge valves will be the first to fail; but with good material a life of several years is not too much to expect. When ejectors are found stopped, it is nearly always from some easily preventable cause or neglect in erection or attendance.

For instance, the set screw holding the exterior balance-weight to the lever may jar loose if not tight, and the same may be said for the set screw which holds the slide-valve lever pin to the lever.

With ejectors that are fitted with flat weights, solids may rest thereon as the water recedes. This may prevent the weight rising in due course for the admission of the air when the ejector is full.

Grease and dirt may accumulate after a time in the automatic valves, or choke the control pipes, and so prevent the valves from being thrown over.

Fracture and breakage or worn-out mechanical parts are practically unknown, and that is why leather

forms the only important item in the maintenance sheet.

SILENCING CHAMBER FOR EXHAUST.

If the 3-in. or 4-in. exhaust pipe from the ejector is permitted to discharge direct to the atmosphere the resulting noise will disturb the surrounding inhabitants—in fact, much in the same way as the exhaust from a gas engine—therefore some form of silencer is required.

When an underground silencing chamber is provided into which the exhaust discharges before escaping by a vertical column, care must be taken to keep this chamber free of water by a drain of not less than 2 ins. in diameter. If this is not done water will accumulate in the silencing chamber, and the exhaust air, unable to escape, will prevent the ejector filling. If the ejector does manage to get a discharge, the water will be observed coming out of the top of the column.

BLOW THROUGH.

If the balance weight shifts its position on the lever, or other similar preventable mishap takes place, the ejector will 'blow through,' and this will stop the ejectors working, but it is known at once at the power house. Again, an ejector may 'blow through' and continue working from either the inlet flap valve being held open by long sticks or bricks, or by the delivery valve being held open in the same manner. In the former case the water blows back into the inlet manhole and is easily detected; in the latter case the ejector is filled from the rising main by the water it has just discharged—that is to say, it is perpetually discharging the same water. This again is easily detected by the inspector, from the large number of strokes the ejector counter has recorded,

Valve-face leathers that have perished and not been replaced will often be detected in the same way.

With large ejectors discharging city sewage these faults are extremely rare—once perhaps in a number of years—but they are not uncommon when extensive sewer construction is in progress, and the ejectors are used to keep the excavation dry for sewer laying. In spite of orders and instructions, every article, from drain stoppers, masons' trowels, and even iron buckets, have been removed from ejectors under such conditions.

Sand and Stones in Ejectors.

If the ejectors are only working at a minimum pressure, road metal may accumulate in the base and interfere with the descent of the weight.

In the same way when draining excavation trenches it is possible for liquid clay and sand to fill up the ejector, when it is not surprising the balance weight fails to operate.

Choking of Ejectors.

With large sizes it is unknown. With small sizes it is a constant nuisance if the ejector is dealing with much refuse, garbage, etc. In such situations it is far better to erect one medium size ejector than a pair of small ones. In situations where ejectors do not take refuse, the small sizes are no doubt as reliable as the larger ones.

Floating Matter.

In localities where ejectors take the effluent from factories, special causes of obstruction sometimes occur. For instance an excessive accumulation of grease in the crown of the ejector will prevent the float rising, and

cases have been known where ejectors have gradually become full of corks and cotton waste.

Though the ejector will effectually expel suspended matter and solids at each discharge, the lever should be occasionally held down to get rid of the lighter matter, if there is reason to believe an excessive quantity exists. Small corks and similar very light articles will at times be drawn up with the exhaust air into the piston valves. There is a strainer fixed in the exhaust pipe, close to the body of the ejector, to prevent this, but the sudden shock of the exhaust will displace it if not very firmly fixed. In the same way moisture, grit, and dirt will also be drawn up, and it is the exhaust valve from which most of the leakage occurs. Therefore, if the ejectors are very slow in discharging, there is a higher percentage of leakage from this cause. They should be examined every few months, to see if any serious pitting of the valve face has taken place.

Leakage through Slide-valve Box.

When the ejector is blowing off, air leakage can sometimes be detected from the slide-valve box. This is as a rule caused by ill-fitting piston-valve leathers, which allow the air to pass into the control pipes. Or sometimes grit will be found lodged under the slide valve or a burr formed by the lever on the valve seat. Once a month all cup leathers, slide valves, piston valves, and ejector valves should be examined.

Examination of Ejector Valves.

It must be remembered that though ejector inlet and outlet valve boxes have to be examined by the small inspection cover provided for the purpose, it is by no

means so objectionable as examining the interior of a pump drawing from a sump.

Firstly, because before removing the cover the ejectors can be completely blown out by holding down the exterior balance weight, and secondly, there is no collection of sewage to putrefy. That is to say, the ejector always keeps the sewers dry; thus the sewage is always fresh and decomposition has not had time to set in.

Stopping Ejectors.

To stop an ejector the inlet valve should always be closed and opened to its fullest extent when working, as heavy articles and refuse may lodge in the groove of the sluice-valve body.

False Discharges.

When ejectors have been at rest and the manhole has become nearly full—that is to say, when there exists a 'head' on the inlet—some types are liable to have the internal weight raised by the violent inrush of water, so that the ejector discharges when it is only one-third full—that is, it will make a number of false discharges. The result is a great waste of air, as it will take a very much longer time to regain normal levels.

When starting an ejector under such conditions, it is always prudent to regulate the first discharge with the inlet sluice valve. If the internal weight happens to be ill-balanced with the external weight, this fault may cause a lot of trouble, but it is very easy to detect and remedy by one familiar with the apparatus.

Ventilation of Tubbing.

An ejector tubbing or well should always be provided with an air scavenging pipe as, like all underground

chambers, dampness cannot be avoided, and the condensation of the atmosphere on the exhaust pipes, owing to the cooling of the expanding air, keeps the machinery in a dripping condition. In hot climates an unbearable atmosphere to work in would exist without these pipes. In very cold climates precautions have to be taken against freezing, as if ice forms in the valve ports the pistons will not throw over.

Painting Machinery.

Too much stress cannot be laid on the importance of painting the interior of a cast-iron tubbing and the machinery it contains; but this must be done in the first place before the cover is placed in position and the ejectors used.

Once used, the interior is never free from condensation water. There are several excellent anti-corrosive fluids or paints on the market, and the interior of the tubbing should be painted white, soon after sinking, when it has become perfectly dry. All ironwork as soon as it is erected should also receive two coats after having been carefully scraped. If this work is left till the ironwork is once rusted and pitted the paint will invariably peel off, and the lighter sections of the wrought-ironwork, like $\frac{1}{4}$-in. piping and ladder rungs, will in a few years completely perish. In the erection of the machinery all bolts, sluice-valve gates, spindles, and such-like items must be greased before they are put together, or hours of labour will be lost in wrestling with immovable valves and rusted studs.

Entrance Covers to Tubbings.

An ejector tubbing is as a rule sunk directly beneath the street, therefore it is necessary to provide a very

heavy form of iron cover to withstand the traffic. It is hardly practicable to make these covers water-tight, as they frequently have to be opened, and owing to their great weight cannot be a close fit. Any suggestion of sticking must be avoided.

Owing to the surface water finding its way between the cover and the frame, it is difficult to keep the machinery in a clean state.

However, in nine cases out of ten, there seems to be no reason why the tubbing should not be so situated that the entrance cover could be placed on a street island or central footwalk, in which case a light type of cover could be used, and a great deal of the deterioration of the wrought-ironwork such as staging and ladders avoided. Again, it dispenses with a third hand necessary for inspection. When large valve covers have to be taken off, it takes two men to handle them, and if the entrance is in the centre of a busy street, as it often is, it takes a third hand to guard the opening.

To arrange the inlet manhole and the entrance cover of the tubbing so that the cover is a few inches above the street level, such as on a pavement, is just one of those small items which cost nothing extra in construction but are the means of saving hundreds of pounds in maintenance in years to come.

Reflux Valves.

The reflux valves on the rising main should always be placed in an accessible chamber and not buried beneath the macadam. And here, again, if the cover of this chamber is placed on the footwalk expense will be saved in construction and maintenance. It is not always possible to arrange for this chamber in the most suitable place for inspection purposes ; but when such valves are

placed beneath the streets, without means of access, the asphalt or wood paving, or whatever the surface may be, has to be broken up and the cost of relaying debited to the maintenance of the ejectors, but with a removable cover no expense is involved. Some engineers do not consider them a necessity, but they are a valuable safeguard against the ejector discharging the same water over and over again when the delivery valve does not close properly owing to some obstruction.

Air Valves in Tubbing.

Whatever the particular type the ejector may be, it is highly desirable that the automatic air valves should be placed in the neck of the chamber as high up as possible. If this is not done and the manhole from any cause becomes full of water, such as in the case of a burst water main or extraordinary floods, these valves will become full of water. The water passes up the air pipe from the ejector into the valves, and instead of the ejectors being able to work at their maximum speed when they are most required, their action will be delayed from this cause, not only by water, but by floating matter which may completely choke up the small control pipes. Again, if the valves are placed close to the body of the ejector they are easily submerged in times of flood, and the ejector cannot be started till the tubbing is baled out.

Underground Obstruction.

In every city, it must be borne in mind, much of the 'underground space' is occupied by water mains, gas pipes, electric cables, telephones, etc., and in the actual marking out of the ejector station, in spite of informa-

tion and site plans, the discretion of the engineer has to decide the most suitable position.

When possible it is desirable to avoid the expense of diverting pipes already in position, but the best position for the tubbing should not be sacrificed for such reasons. A few extra feet to the length of the inlet pipe from the manhole to the ejector is of no consequence to its efficient working.

Disc Valves.

The manhole end of the inlet pipe to the ejector should always be provided with a disc valve and a long rod reaching up to within a few inches of the cover, especially with small ejectors, owing to their being more liable to be choked with refuse when they stop working for want of water and the manhole fills up.

Under such conditions it is first necessary to close the inlet pipe, and this can only be done by means of the disc valve and rod in the manhole. It is obvious, if the cover in the inlet pipe in the tubbing is opened before this valve has been let down, the chamber would be flooded with sewage. With large ejectors the necessity for this operation may never occur, but it is one of those precautions in erection that should never be omitted.

Air Mains.

The efficiency of an ejector system largely depends on the care with which the air mains are laid and tested. Too much care cannot be expended on efficient supervision in caulking the joints and 'bedding' the pipes on trench bottom, and not on filling as is often done.

Extra money spent on construction means less money spent on repairs and maintenance. There is no section

of the work which may prove so expensive in maintenance if badly carried out.

Leakage from the air mains is indeed considered to be the greatest objection to an ejector system, but at the low pressure maintained there is no reason why this should be excessive or amount to such a figure as to destroy the value of the whole system.

It is true a large volume of air will escape from an exceedingly small hole, but before the mains are covered in it is easy to detect and easy to remedy.

It is expensive to excavate and recaulk pipes, but this should only be done if the leakage exceeds a certain percentage of the whole volume compressed. Below a certain figure the extra cost of maintaining the pipes 'air-tight' would not balance the saving in fuel. The higher the cost of fuel the more economical it is to spend money on maintenance. If fuel could be purchased at a very cheap rate, say 15s. per ton, it would not pay to keep leakage down to 2 per cent. or 3 per cent.

Usually a 10 per cent. loss is looked upon as good enough for a 35 per cent. efficiency over the whole system. At 22 lbs. pressure it is quite possible to maintain a 5 per cent. loss only, and with expensive fuel it pays to do it.

Laying Air Mains.

At first sight there would not appear to be many difficulties to contend with in laying a cast-iron spigot and socket pipe a few feet below the surface. In open ground there are not, but when it comes to crowded cities, with narrow streets and subsoil obstructions of every description, it is a matter of deciding equally awkward alternatives on the spot, as to which is the best line to take and least expensive. Air mains must

be laid so that they can be excavated at any time. It is no use laying them under tram lines, or in such close proximity to stone walls and other pipes that the joints cannot be recaulked. It should not be overlooked there may be no indication on the surface of the street of what is underneath, and a hundred or two hundred yards of trench must be marked out and opened up at a time, and the whole trench may have been excavated before it is found that the particular line, which may be between a footwalk and a tram line, is already occupied by a water main or other pipe.

When any doubt exists the best plan is to keep two or three men sinking trial holes on the proposed line well ahead of the work. In old cities it is often exceedingly difficult, if not impossible, to obtain complete drawings of the exact position of what has already been laid beneath the streets.

Again, new streets and new alignments of old streets are constantly taking place. Private roads are converted into public streets, and unrecorded cesspools, cellars, foundations, and similar obstructions are incessantly met with and have to be circumvented by the ingenuity of the inspector.

Estimates and specifications only provide bends that can be indicated on site plans, and cast-iron pipes must be laid more or less in a straight line ; without special bends, work may be hung up or have to be relaid.

As a rule, cast-iron pipes are quoted for by the yard or metre, laid in place with a certain minimum cover. However, as the work proceeds it is invariably found that contractors claim extras, as it is often not possible to lay the pipe with the stipulated cover owing to their having to dip under water mains and other systems already in position.

Again, curbstones have to be moved, foundations cut through, supports built in, old culverts crossed, and special protection taken for the pipes having to pass under railways. If the specification is not very precise, and the rates clear, such extras will amount to a large figure in the monthly certificate.

A gang of pipe-layers consisting of eighty men, including lead-runners and caulkers, besides all necessary labour employed on such work, will lay as much as 100 yards of 6-in. spigot and socket pipe per day—that is, excavation, laying, and jointing and refilling with a 2 ft. 9 in. 'cover.' This would be on the footwalk. In heavily metalled streets the rate could hardly be maintained.

There is no doubt whenever possible it is preferable to lay air mains beneath the footwalks. Less cover is required, and they are free from the dangers of steam rollers and heavy traffic. Also a lighter type of surface box for valve keys is required than if placed in the street, to stand heavy wear and tear.

In laying mains of this description through populous streets many of the service lead water pipes to the houses will be broken by the labourers' picks. The same may be said for the gas pipes, and the Company's turncocks and plumbers should always be present to prevent excessive waste. Such pipes are easily repaired, but they should be done at once by men on the spot to avoid inconvenience.

Caulking Pipe Joints.

To make an efficient joint with spigot and socket pipes, the following materials are required: tarred yarn, stiff clay, and soft pig lead. Scrap lead that has been remelted many times is hard and quite unsuitable for air-

main joints. In using such lead there is always the danger of the caulker bursting the socket of the pipe with the caulking tool in making the joint tight. The pipe socket is usually four inches deep. A gasket of tarred yarn is rammed home round the spigot end of the pipe after it has been inserted in the socket. A special band or short length of one-inch rope is smeared with clay and placed round the socket, in order to close the open end—the plastic clay effectually makes a 'tight' joint—and a small space is left on the top for pouring in the lead. The lead must be hot, but not burnt. If too cold it will fail to run evenly and leave a spongy ring, in which case a sound joint cannot be made. Bad running is the chief cause of leaky joints. A well-run joint can be caulked to refusal. With good workmen there are few trimmings; they should not be cut off, but permitted to 'fall away' as the caulking tool travels round the joint.

Testing Air Mains when Laid.

Contractors usually favour portable steam compressors for testing purposes. Two hundred yards is the maximum length that should be tested at one time. The longer the length the better the result should be, owing to the expansive nature of the compressed air. To test the completed length, blank flanges are clamped to each end of the main with the necessary connections for air supply and pressure gauge. The engine is started and the pressure raised to the stipulated figure, when it is stopped and the fall in pressure in one hour noted.

If the compressor happens to be in the next street and not in view of the gauge, it is as well to see that it is not restarted at any time during the test. If the jointing has been well done, it will be found that with an initial

pressure of 50 lbs. to the square inch the loss will not exceed 1 lb. or 2 lbs. per hour.

Detecting Leakage.

The application of soapsuds to all joints will immediately indicate any leakage. It is by no means uncommon to find that if leakage exists in spite of all the joints being sound, a pipe has been cracked in transport or a socket in caulking. Some settlement is inevitable, and it is a wise precaution in estimating to allow a sum for recaulking. After twelve months or so, when once the pipes have become firmly bedded, the joints alone can be opened up and recaulked with little fear of further leakage. Care should be taken that contractors do not lay odd lengths of pipe, or much difficulty will be found in locating the joints from the surface.

The smaller sizes of cast-iron pipes give more trouble from leakage and fracture than those of large dimensions. The joints are more difficult to caulk, and the pipes will not stand any strain from uneven bedding.

In some cities where the subsoil contains many old foundations, even a bad leak running away with 100,000 feet of air per day will never come to the surface and is only located by sectional testing. With a properly organised staff this is not a long operation. A leak of such magnitude immediately causes the driver at the power house to increase the speed of his engine to maintain the air pressure. The outside staff are warned and are soon able to locate and isolate the section. In some cases essence of peppermint may be put into the air main and the leakage detected by smell, but with tarred streets and asphalt paving this is not very successful. The best method is simply to locate the worst sections between stop valves, excavate the joints from

the two ends and, when the gauge indicates the pressure is again normal, fill in and leave the remainder of the pipe.

Filling Trenches and Rammers.

Subsequent settlement of air mains depends very much on the method of filling the trench. As before stated, the pipes should be laid on unbroken ground—that is, on trench bottom—but it is not always possible to do this. The ramming of the earth round the pipes is of extreme importance but rarely given the attention it merits.

It is a common thing to use ordinary mushroom-headed stone rammers of 8 ins. or 9 ins. in diameter; but they are not suitable, and will not 'pack the earth' below the pipe. Subsidence and leakage are the result. The rammers for this class of work should be of the pattern used by moulders in the foundry, with small rectangular heads, and weigh 6 lbs. or 7 lbs. By using such rammers on either side of the pipe it will be found the earth can be packed against the underside of the pipe as efficiently as the moulder packs the sand round his patterns. Soft earth only should be placed immediately against the pipe. Large stones and dry rubbish, which the soil often consists of, will not do.

Water in Air Mains.

In all long lengths of air main a certain amount of condensation takes place. Though most of the water will, no doubt, pass out through the ejectors as they are always at the lowest levels, drain cocks should be provided in all sections where water is likely to collect. A saddle-piece should be clamped on to the pipe, a hole drilled and tapped before the pipe is laid, and a $\frac{3}{4}$-in. pipe

with brass plug cock brought to the surface, over which is placed a cast-iron surface box.

Air Stop Valves.

One of the chief causes of leakage is due to unsuitable stop valves on the air mains. To prevent leakage these require to be of the type that cannot leak past the spindle when the valve is open. Packing soon perishes underground, and there is no room to repack glands through a key box.

The ordinary type of steam valve with loose valve and packed stuffing-box is not suitable. It soon leaks, and grit and moisture often make it inoperative.

Plate XVI. shows a type of valve that has proved very satisfactory in practice on underground air mains.

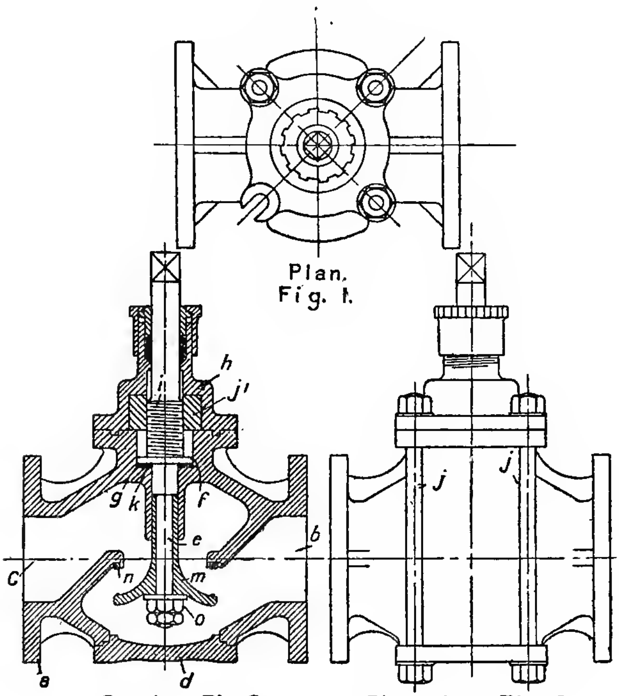
It is simple in construction and easy to dismantle for cleaning. All valves that have to remain for years underground soon become corroded, and the studs frequently break off when the nuts cannot be removed.

In this valve there are no studs. Four bolts fit into slots in the cap and bottom cover. The principal feature, however, is the security from leakage when the valve is open.

The air-main valves remain open for years; in the ordinary type the packing perishes and the air leaks past the spindle. But in this valve a collar is turned on the spindle and screwed hard down on to a copper face when the valve is open. The nut for operating the valve is removed from the fluid, and the single central guide with the valve attached does not become fouled, nor is it liable to jam as sometimes happens with ordinary designs. The gland and stuffing-box are provided for testing purposes so that the pressure can be applied in either direction, and the valve can also be used as a regulator if so desired.

Referring to Plate XVI., Fig. 1 is a plan, Fig. 2 is a section, and Fig. 3 an elevation. *a* is the valve casing, *b* the inlet, *c* the outlet, *d* the plug in the casing. The valve stem *e* is provided with a collar *f*, adapted to bear on the face *g* of the casing *a*. *h* is a hollow cap, through

PLATE XVI



Section Fig. 2. Elevation Fig. 3.

AIR STOP VALVE

which the stem *e* passes. The stem *e* is screwed at *i* and engages with a nut *j* disposed in the cap *h*. The cap *h* and plug *d* are clamped to the casing *a* by bolts *jj* which pass outside of the casing. *k* is the copper washer between the collar *f* and the face *g* of the casing. *m* is a hollow valve on the stem *e*, adapted to bear on the

valve seat *n*. *o* is a nut for securing the hollow valve *m* on the stem *e*.

Valve Chambers.

In large systems the expense of building several hundred masonry valve chambers amounts to a large figure, and may well be omitted. Even the best of masonry chambers does not prevent extensive deterioration, and unless they are large and deep a valve cannot be removed without breaking the brickwork.

A satisfactory method of dispensing with the brick chamber is as follows.

Having well greased both nuts and spindle, and tarred the valves, bury the valve to the level of the cap. Place several bricks round the cap and rest a stoneware pipe upon them. Fill in the earth, place more bricks round top of the pipe, over the spindle, and on these rest the cast-iron surface box for inserting the key. Fill in round the box and make up the road, and there will be no occasion to disturb it or anything more than the expense of excavation if it is desired to remove the valve. This method will save a great deal of expense in construction and maintenance, especially if the type of valve shown on Plate XVI., page 128, is utilised.

Accident to Air Mains.

Owing to the low pressure there is no fear of an air main bursting in the ordinary sense.

Accidents will occur now and again: a steam roller will fracture a pipe if the ground subsides in remaking the street, and air mains break from the tubbings after heavy rains. Such mishaps are easily detected. Again, gas companies' mechanics sometimes mistake the air mains for gas mains when they are making new connections

to street lamps and dwellings, and do not discover the difference till the hole has been cut in the pipe.

If mains refuse to pass the volume of air it will probably be found that a valve has become jammed in its seat, the nut screwed off, and the turn-key instead of opening the valve withdraws the spindle from the hole.

Laying Rising Mains.

In the laying of sealed-sewage mains the precautions adopted with water mains should be observed, but at all bends an inspection opening should be provided and extreme care taken that a 'badger' is drawn through the pipes before they are closed. If this is not done articles are liable to be left in the pipes during the process of construction. Whole bricks from 6-in. mains have been removed, and timber struts 3 ft. long and 4 ins. square, sacking, balls of caulking yarn, and suchlike articles. Again, lead passing through the joint into the invert of the pipe is sufficient to form an obstruction after some months' work. When the pipes are first put into use the effluent passes, but after a time the accumulation of solids completely chokes the main, and there is nothing for it but to cut out the pipes and relay them.

Back Pressure in Mains.

In cases where more than one ejector discharges into the same main by long lengths of branch pipe, care must be taken that these small mains are not choked by back pressure, or many yards of pipe will become filled with solid matter which can only be removed by cutting out. The remedy for the trouble is obvious.

It is surprising what large articles will pass through these pipes without stoppage. It may be taken for granted that any substance that will pass through the

ejector will pass up the rising main, provided there is sufficient water and no constructional fault.

Fouling of Mains.

During the first two or three years a certain amount of fouling of the mains will take place, and more pressure will be required to discharge the ejectors. After the pipes are coated inside to a certain extent it does not appear to be progressive.

Locating Stoppage in Mains.

With a choked main the reflux valve is first opened, to see if all is clear. Then the first inspection chamber is excavated, and a pressure gauge fixed in the cover. If there is no pressure the stoppage is down stream. The main is excavated half-way between the chamber and reflux valve, a hole drilled, and pressure gauge fixed. If there is still no pressure another hole is drilled, and so on till the block is located.

Air Lock in Mains.

In cases where a rising main is laid at a steep grade and suddenly falls, it is necessary to provide an air-cock just beyond the highest point, if not a permanent atmospheric pipe, or trouble will arise from air lock and difficulty will be experienced in making the ejector discharge under normal pressure.

Inspection Openings and Bends.

As a rule inspection openings are provided in sealed-sewage mains at all bends, and every 100 yds. in pipes less than 10 ins. in diameter, though 90 per cent. of them will certainly never be required. The covers should be drilled and tapped for a pressure gauge, as when the

main becomes choked they may save the cover being removed by indicating if the block is up or down stream.

Again, all bends should be backed by timber struts firmly driven into the ground, or by a block of concrete, as the pressure is liable to force the joint and cause leakage. Care must be taken that the concrete does not rest on the pipe, or settlement of the masonry will start the joint and cause leakage.

Scour Valves.

In all long lengths of main there should be a scour valve that can discharge into the gravitation sewers, as it is not only advisable to discharge any solid matter from time to time that may collect in the depressions, but if the sewage main has to be opened it is an extremely unpleasant business, flooding the street with crude sewage. At all junctions sluice valves are required, and these must be operated periodically or they will become absolutely fast. All valves should be right-handed and of the same pattern, and covered over with a surface box as already described, for air stop valves.

Bursting of Mains.

This is unknown from internal pressure. Joints have been known to give out and inspection chambers crack, but if laid with 3-ft. cover there is practically no danger unless a steam roller or such heavy vehicle cause subsidence.

Indicator Plates.

Sluice valves, air valves, and inspection openings should all have their positions indicated by an iron plate fixed in the nearest wall, showing the distance at which it is located, much in the same way as the fireman's water cocks.

CHAPTER VIII

THE SANITARY EFFICIENCY

The sanitary efficiency, though left till last, is by no means the least important. Properly speaking, it should be dealt with by experts in public health, as it is somewhat outside the province of the engineer to say what is a public nuisance and what is not, or what is dangerous to health, and what is, and what is not an offensive odour. In fact, the precise definition of 'efficient sanitation' in the matter of the collection and conveyance of domestic sewage is, and will remain, a matter of opinion; but the last word invariably rests with the public health authorities, and it is the engineer's function to provide the means to conform with the stipulations laid down.

On his skill and experience will depend the provision of the most efficient means of carrying out the work to be done with the funds available.

The ideal, though unattainable, must be steadily kept in view. Make certain of the essentials either large and small, and economies will suggest themselves as the scheme is designed.

Gravitation Scheme.

Though the simple gravitation scheme has been excluded from these pages, it is obviously adopted without question whenever the necessary levels permit; but it must not be taken for granted that such a scheme always

possesses sanitary efficiency, or in exceptional cases is the cheapest to construct and maintain. For instance, in situations where a gravitation scheme necessitates sewers of great depth in water-logged soil, and little fall can be provided, the expense of excavation and de-watering, together with cleaning choked sewers, difficulty of flushing, and repairs, will amount to a higher capital cost and maintenance than a system of shallow sewers with efficient and reliable means for conveying the effluent to the disposal works.

Or again, it is not unusual to find localities in which some sections are able to be drained by gravitation, while others require some means of raising the sewage into a high-level sewer.

There is no object in wasting power to raise sewage when it will flow by gravitation to the desired outfall, even when by so doing some expense can be saved in the original construction.

A single-main outfall with a single-disposal works can be allowed for with the exception of those cities that discharge their sewage direct into the sea. Whether this method, however, can be described as coming within the definition of 'sanitary efficiency' is a subject that will not be discussed here.

No two undertakings are precisely alike. Each case must be considered independently on its merits. A satisfactory system for an urban district in Europe may be a danger to health in semi-tropical countries.

The Subsoil.

The nature of the subsoil in the area to be drained should be carefully studied. The sanitary efficiency will depend to a great extent on reliable information from this source.

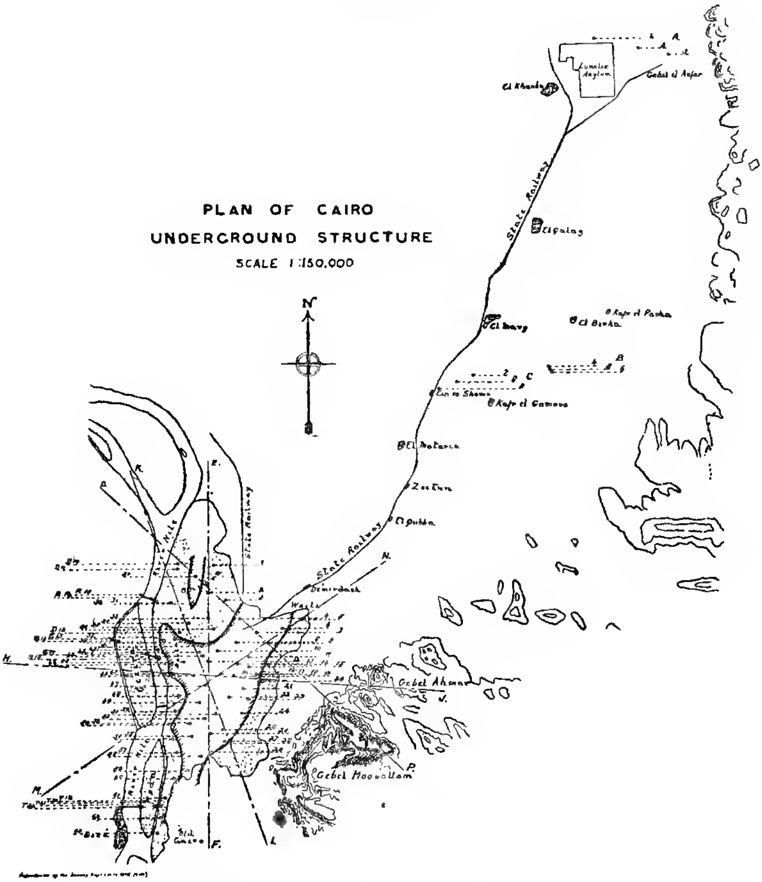
However, few authorities care to go to the expense of mapping out a whole district before commencing operations, as unless a very regular geological formation exists, it would entail the sinking of many trial shafts and boreholes. Nevertheless in some localities it is a question if the extra expense would not be more than covered by the definite information on which estimates could be drawn up, and the saving in sound construction in the first instance.

In a sectional scheme of great extent there is little doubt that an excavation on the site of the proposed ejector stations is well worth the trouble. Instances have been known where sites have been selected and operations carried so far, that it has been cheaper to sink a tubbing through solid rock than to alter the whole sewering scheme of an area. To excavate rock in a compressed-air chamber by candlelight is an extremely costly and tedious business, and the only alternative is to go to the heavy expense of keeping a steam pump constantly at work with the difficulty of disposing of the water in crowded streets.

The advantage of possessing complete information of the subsoil will be understood from a glance at the plan and ground sections shown in the following diagrams. Plate XVII. shows a plan of the city of Cairo on which is marked the sites of sixty-three ejector stations. The numbers prefixed by a capital letter refer to deep boreholes and excavations made in the construction of the bridges that span the Nile. Plates XVIII. and XIX. show sections through the soil, the vertical line indicating the position of an excavation. These diagrams, however, were made from the information derived in sinking the cast-iron tubbings and not from previous excavations, but their value was obvious in the construction of the deeper sewers.

The various strata of the Nile valley may not be precisely reproduced elsewhere, but river deltas have many points in common, and the cities standing thereon are subject to many of the same conditions.

PLATE XVII



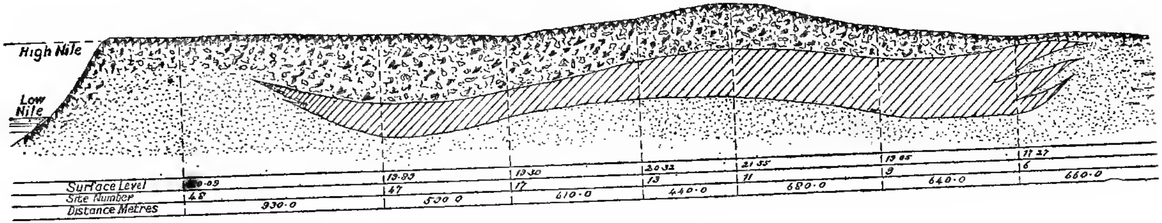
On looking at the plan of the city, Plate XVII., the area of the impervious clay deposit will be noticed. It is that portion within the hatched outline. The sites appear to be selected in a haphazard manner, but it must be

remembered that they are situated for the most part on the flats, and in the depressions which formed convenient localities to which the sewers would gravitate. This will also explain the inequality of the sections taken and the reason why the imaginary lines do not precisely bisect each site. However, they are so numerous that this inaccuracy can hardly affect the general outline as depicted. In such diagrams extending for miles, it is obvious that the vertical scale must be larger than the horizontal scale in order to bring into prominence the correct levels, and their relative proportions should not be overlooked. The area covered is approximately 6×3 miles. On the west is the Nile and to the east the stony desert.

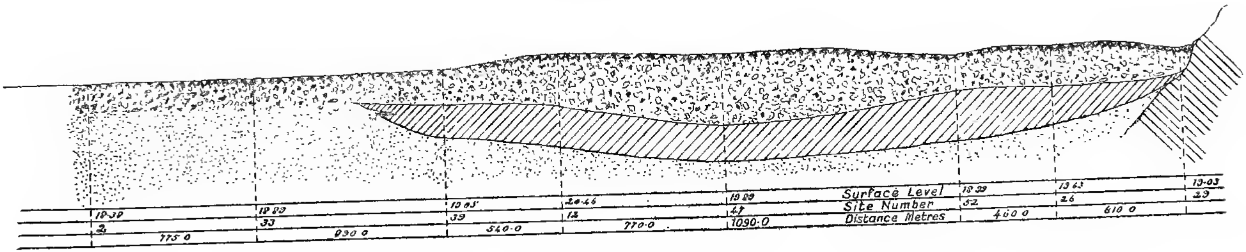
The index letters on the sections correspond with those upon the plan, and the excavations have been numbered in such a manner that any particular site can be located at a glance in spite of their irregular position. The general characteristics of the soil are well illustrated in Plate VIII., page 26, and may be summed up briefly as follows. Commencing with the surface we have in most cases a deep layer of builders' rubbish. The remains of house after house have decayed, fallen, and been trodden under foot till the original ground levels have been entirely obliterated and artificial hills have appeared. Virgin loam is seldom met with except in outlying portions of the city. Secondly, a natural deposit of stiff plastic clay which varies in thickness from 3 feet to 12 feet. Thirdly, a vast mass of interbedded fluid sands, the upper layers of which are frequently as fine as ground pepper, and coarser varieties beneath from which an inexhaustible supply of water can be drawn.

The most remarkable feature of these deposits is without doubt the basin or depression in the clay bed, which can

PLATE XVIII



Section M.N.



Section E.F.

Ground Sections of Cairo

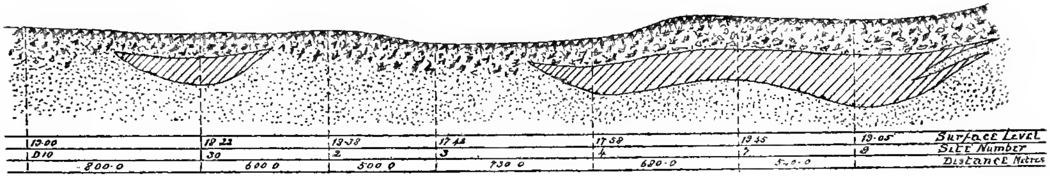
be clearly seen in section E.F. (Plate XVIII.). At least this is how it appears in the diagram, but it is in reality an extensive lake or lagoon which underlies the centre of the city.

On sections M.N. (Plate XVIII.) and H.J. (Plate XIX.) the high and low level of the Nile will be noted. Obviously when the annual inundation rises above a certain level, the lake is replenished, while throughout the year (before the drainage scheme existed) it is incessantly fed by the drainage from the houses. And this water must either be absorbed by the accumulated rubbish, or flow over the edge of the basin into the Nile through the porous soil.

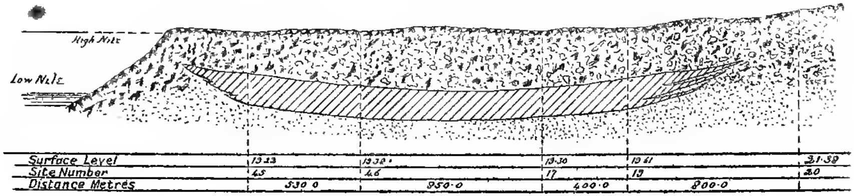
Section M.N. is of particular interest, as the first and last excavations on the surface show what is practically true ground level, and the lowest level is that furthest from the river bank. A certain amount of water always overlays the clay bed, and is often only a few feet from the surface, but if the clay bed is pierced not only water but sand will continue to rise as fast as it is removed. For this reason excavation in such soil is very costly without the use of compressed air.

From the sanitary point of view, the advantage of shallow sewers is also obvious under such conditions, as stoneware pipes that are laid in a porous soil which is alternately saturated and drained each year are liable to some settlement which cracks the joints. The result is the subsoil water leaks into the pipes when they are submerged, and the sewage leaks out when the subsoil water subsides. It is almost unnecessary to state, if the sewage leaks out of the sewer in any quantity in porous soil, the state of the ground is little better than if percolating cess-pits existed. It must however be pointed out that because a large volume leaks in, it is no proof that an equally large volume leaks out. In fact, there is no

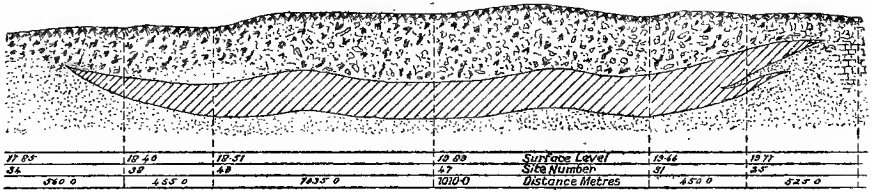
PLATE XIX



Section O.P.



Section H.J.



Section K.L.

Ground Sections of Cairo

question that it does not, provided the ejectors are kept working and no 'head' is placed on the sewers. When stoneware sewers are placed under an external pressure of 10-ft. head of water, it is clear that the whole circumference of a cracked joint will admit water; on the other hand, a sewer in the same condition in dry soil, running a third full, will show insignificant leakage in comparison.

Conditions for Sanitary Efficiency.

Atmospheric conditions must be studied, prevailing winds carefully noted, nature of the soil, source and method of water supply, and particular attention given to providing such arrangements as will facilitate future extensions. Again, if the district is subject to a heavy rainfall, it may be advisable to adopt a separate system for surface water, as distinct from house sewerage, especially if the effluent has to be raised to the disposal works under a high pressure. If a single system was adopted in such cases, the cost per head of the population would amount to an unreasonable figure. In the majority of cases, rain water may be discharged into a tidal way or river without offence—that is to say, what is usually termed 'flood water'—but provision has to be made for street sweepings to run into the house sewerage system.

The initial expense of laying separate sewers for each purpose is heavy, and a series of overflows is the most favoured arrangement. With the progress of sanitary engineering the question of sanitary efficiency comes to be more and more considered, and the more densely a district is populated the more difficult it is to find sites for purification works and pumping stations. No scheme that does not provide for purifying the effluent can be entertained at the present day. It is an essential part

of the whole, and second only in importance to the rapid conveyance of the raw sewage from house sewers beyond the precincts of habitations.

If the grade to which the sewers are laid is not sufficiently steep, putrefaction of the effluent will take place and noxious odours will be disseminated; but in the absence of natural fall, deep sewers must be laid to avoid this unless the sectional system is adopted.

Sectional System.

Briefly, the sectional system of sewering a town or district is simply dividing the district up into a number of suitable sections. The lowest site in each section is chosen for a sump or collecting manhole, and all street sewers in the section converge to this spot. Either a pump or an ejector is located at this spot and the sewage is pumped into a sealed cast-iron main, which discharges the liquid at the disposal works, or into a high-level gravitation sewer, if the site of the disposal works and levels of the surrounding country permit. Let us analyse the differences between the pump and the ejector for such a purpose and see why one has a better sanitary efficiency than the other.

The outstanding difference is that a pump requires a cess-pit or sump to draw from, and a screening chamber to collect refuse which has to be periodically removed and handled. The level of the liquid in such a sump varies, and large surfaces to which the floating matter in the effluent clings are exposed to putrefaction. The cleaning of this sump and screening chamber is not only repulsive but a dangerous occupation, as lights are invariably needed to work by and explosions are liable to take place from foul gases with disastrous results. With the ejector as previously described, there is no sump.

The sewer discharges into the body of the ejector, which automatically forces the effluent, together with all refuse, into the rising main at frequent intervals.

Grade of Sewers.

To ensure sanitary efficiency, especially in tropical and semi-tropical climates, this is a necessity, and the sewers must be laid at such a grade that the effluent arrives at the ejector before putrefaction sets in. Grades of 130 to 150 in street sewers are not unusual, and this gives a velocity that permits of this desirable end being attained.

It will be observed that the ejector inlet shown on Plate VIII., page 26, is placed at such a level that the sewers are kept drained. No collection or putrefaction can take place in the sewer, therefore no foul gases are formed. Fresh sewage is inoffensive. The mechanical apparatus that will deal with the sewage as fast as it comes down the sewers, has a higher sanitary efficiency than an apparatus which permits collection and decomposition, and the ejector is far superior in this respect. In durability and freedom from breakdown it has no equal and supervision is reduced to a minimum.

The pneumatic ejector is to be preferred to a pump, whenever the locality is of such a nature that the capital expenditure and cost of maintenance is not out of all proportion to the results obtained. Even in small installations the points are in favour of the ejector.

Reasons of Preference for Small Pumps.

That small centrifugal pumps are so often installed in country towns and large villages is almost invariably due to the high efficiency on trial results that the maker is able to put before the consulting engineer, and the

reduced initial outlay on machinery, without regard to the efficiency of the pumps, in a few years' time, or the cost of deep sewers. Again, great weight is often attached to the fact that the ejectors would have to be kept continually at work to prevent the sewage backing up in the sewers, whereas with a pump two shifts are avoided, the sump being of such a capacity that it can be permitted to fill up during the night after having been pumped out in the daytime. But the flow of sewage in such places during the night is but a small percentage of the daily flow, and there is no reason why the sewer should not be enlarged at the discharge end, with a water seal upstream to avoid any unpleasant effects of sewage accumulation. It would be flushed and drained automatically in any case, thus obviating the periodical removal of refuse and cleaning of the sump which takes place with pumping installations.

Let us take an example.

Typical Example of Small Sewerage Scheme.

A large village consisting of groups of houses in low-lying ground, and others on high ground, is advised by the local authority that a drainage scheme must be carried out and maintained by the rates. The Local Government Board, or whoever's duty it is, appoints an engineer to survey the place with a view to laying down sewers and finding a suitable place for disposal works.

He soon discovers that the greater part of the sewage will have to be raised by some means or other to the purification works, and no means must be spared in his estimates to keep the cost down per head of the population to a reasonable figure, if he is not to put forward an extravagant scheme which will be rejected and injure his career.

In all probability he is without experience in running pumps or ejectors, and has little knowledge of mechanics. Therefore the machinery is the direction in which to economise.

What does he do ?

He has two alternatives before him. Assuming the total head with friction is about 45 ft., he has choice of installing small pumps with steam, oil, or suction gas engines, excavating and building a deep screening chamber and sump and laying a low-level sewer thereto, or providing two or three small ejector stations with an oil-engine air compressor.

The disposal works are common to both schemes, but need not be of such magnitude for the ejectors as less surface water would be dealt with. His pumping station and sump must be far removed from habitations, and difficulty may be experienced in finding a site that does not entail the laying of a long length of sewer in water-logged ground.

On the other hand, his ejector stations can be placed beneath the roads in just those spots where there is a local depression to which shallow sewers may converge. His air-compressor station, being quite inoffensive, can be placed in twenty different situations, and the rising main to the disposal works will not be more than 2 ft. or 3 ft. below the surface.

The laying and cost of a cast-iron main may be calculated to definite figures, but deep sewers often run into large sums, from the extra cost of de-watering and heavy timbering to prevent subsidence. He collects what information there is on the cost of machinery and studies the published results of official efficiency trials.

According to these the ejectors, besides costing more

to install, have an efficiency of only 38 per cent. compared to 72 per cent. of a pump.

Obviously, on paper, this represents a large saving in maintenance. What more convincing evidence can an engineer require to put before his superiors or the parish council ?

There is no evidence or information of a conclusive character to disprove his figures. Five or ten years hence is none of his affair. He is only there to estimate the cost, and supervise the carrying out of the work, which will, in due course, be handed over to the parish council. Whatever the cost of running may be will be accepted as inevitable, and the mechanic employed to supervise the machinery will neither have the knowledge nor interest to compile detailed records from which posterity may benefit.

The question of city drainage becomes more and more of an engineering science.

The purification of the effluent has reached a high state of perfection. The grading of sewers for suitable velocities and their precise capacities has been reduced to exact formulas ; but the behaviour of power engines and the apparatus to raise the sewage is too often a closed book to those in authority who are responsible for the construction and maintenance of sewage schemes.

CHAPTER IX

POWER HOUSE

Power House

These notes and records on the efficiency and cost of raising crude sewage by pumps and pneumatic ejectors would be incomplete without some reference to the power house. Important though it is to maintain the ejectors in an efficient state, we can do nothing without the means from which the power is derived. The power house is the centre of the system from which flows the required energy in every direction.

Power Engines Compared.

Whether the installation consists of steam engines, oil engines, or gas engines, the heat is the power and the sewage to be raised is the work to be done.

With the steam engine the heat is derived from the combustion of fuel beneath the boiler which generates the steam for actuating the engine, which converts the fluid energy into mechanical power for compressing the air (which is a secondary power) as a medium of transmission for working the ejectors.

With the oil engine the combustion of the fuel takes place in the cylinder of the engine. In actual fuel consumption for the volume of air compressed there is a great economy, but that is subject to a uniform output at a steady pressure. With the gas engine combustion

also takes place in the cylinder of the engine, but a separate plant has to be provided for the generation of the gas.

For supplying power to an ejector system the first requirements are reliability, flexibility. By reliability is meant freedom from breakdown, from any cause whatever; by flexibility, a great range of speed and power, so that a constant pressure can be maintained in spite of variation in speed.

A good internal-combustion engine will consume 0·50 lb. of oil per brake horse-power per hour. A good superheated steam engine will consume 1·19 lbs. approx. of coal per brake horse-power per hour, or with fuel oil 0·72 lb. per brake horse-power per hour.

Given a sound and efficient steam unit, it will probably be found that the commercial efficiency of the steam plant is not inferior to that of the internal-combustion engine. Indeed, experience shows that the reverse is usually the case. The variation in the demand for power over the twenty-four hours is very great, and during the twelve months greater still. One of the most difficult questions to decide in specifying the machinery for a power house is the number of separate units which should be installed to make up the maximum power required.

The unit that will give the highest efficiency over the greatest range of speed is the most efficient for running an ejector system. The larger the unit the higher the efficiency should be, but there is a limit at which a large unit will run economically at low speeds.

When internal-combustion engine compressors are installed, it is not unusual to provide a by-pass to atmosphere from the compressor, as the speed of the engine cannot be reduced sufficiently when the consumption of air falls to a low figure. But this is, of course,

extremely wasteful, and the economy gained in one direction is thrown away by extravagance in another.

Much depends on the price of the fuel.

The cheapest quality of fuel can be burned under a boiler, but a more expensive grade is required for the internal-combustion engine. When electric current can be supplied at a very cheap rate from water power or some great industrial power station, a variable-speed motor compressor should be considered. The capital cost in buildings and maintenance should be much less, but some form of sensitive air governor would be required to maintain a steady pressure under varying demands. To run an engine, no matter of what type, against a steady pressure makes all the difference between waste and economy, and herein lies one of the chief causes of the inefficiency of an ejector power station; but there is little doubt this drawback is open to improvement, and will be dealt with in the next chapter.

There is no intention of comparing the merits or disadvantages of the various designs of engines and compressors, but it may be remarked that it pays to have machinery of the highest class.

Plates XIV. and XV. (pages 70, 71) show the interior of the large compressor station for operating the Cairo drainage system. They are triple-expansion condensing engines, with double-acting compressors, direct coupled to tail rods from the three steam cylinders, and each compressor is provided with mechanically operated valves for the admission and discharge of the air. While some engineers favour this type owing to their flexibility, others prefer the high-speed vertical type. Such engines take up less room, and can be usually guaranteed to give a higher efficiency. Complicated valve gear of all descriptions should be avoided; each unit should be

complete in itself, and arrangements made so that the engines can be easily started under pressure.

Power-house Design.

The power house should be designed to suit the machinery. That is to say, the foundations of the engines, their spacing, basement requirements for pipes and condensers, boilers and their accessories, must all be carefully drafted out in a general arrangement—plans, elevations, and sections complete, showing every essential, such as dimension of engines, position of chimney stack, economiser, cooling pond, and the various levels at which it is proposed water shall be drawn by the circulating pumps for the condensers and compressor jackets, also the method of replenishing the water supply and arrangements for carrying it away. When these points have been carefully decided and the machinery selected, it is simply a matter of providing a suitable building to cover the plant.

There is nothing more expensive or unsatisfactory than fitting machinery into unsuitable buildings that have already been designed. A municipal power house is neither an orphanage nor a factory, and there is no reason why the architect should not produce as handsome a building as the funds at his disposal permit. The walls must be built to carry a travelling crane, and the doorways made of sufficient dimensions, or other facilities provided for admitting the largest sections of the machinery into the building. There is nothing more exasperating than having to knock holes in a new wall or cut out windows before the engine can be put together.

Foundations for Machinery.

The extent and massiveness of the foundations depends

a great deal on the nature of the soil and type of engine. The foundations must be quite separate from the walls and floors, and the chimney shaft well clear of the building. If the subsoil is water-logged sand, as is sometimes the case, either timber or concrete piles should be employed. The foundations for the engine must be very carefully set out, and the holes in the masonry left for the anchor bolts, by means of wooden templates supporting collapsible wood centres or wrought-iron pipes, round which the concrete is filled in. If pipes are used and it is desired to withdraw them, they must be kept free by slight movement before the concrete sets. If solid-wood centres are built into the foundations for anchor bolts, a great deal of trouble and expense is required to burn them out with hot irons. Nothing can surpass the dressed stone for an engine bed, rubbed down to a perfectly level surface, but the usual method at the present day is to simply pack up the bed-plate and fill in with cement or 'grout.' It is of importance that there should be no delay in this process as cement sets quickly, and the 'grout' must set in a solid mass to be a success. Only the very best brands of cement should be used for the work.

Boiler foundations are often too shallow, especially for water-tube boilers. In the setting for these boilers there is a heavy mass of masonry over a small area. Though the boiler itself takes no harm from some settlement, the steam mains are strained and the joints will be a perpetual source of trouble from leakage. If a serious settlement takes place, it will cause fracture and much damage may result. In front of the boilers ample space must be left for the coal, and a line of rails for the coal trolley.

Ventilation.

With horizontal engines more floor space is required than for vertical engines, but less head room. In the roof ample ventilation must be provided. The ventilators of whatever type should be so designed as to exclude the dust as much as possible. Rows of large windows are both unnecessary and objectionable, but the building must be well lighted. In dusty countries much injury is done to the bearings by the dust coming through the open windows. If the internal walls are lined with glazed bricks an excellent effect is produced, but some authorities do not care to go to this expense.

Engine-house Floor.

A tiled composite floor of steel joists and concrete will meet all requirements, but immediately round the machinery and covering all flanged pipes, also accessories in the basement, cast-iron chequered floor-plates should be arranged. They must be supported on steel joists, which can be dismantled without interfering with the floor. These removable plates are of great importance, as they not only admit light to the basement when removed, but enable any section of the machinery to be dismantled without expense or trouble. Again, oil dropping from the valve gear is easily wiped up, which would otherwise leave untidy stains on the tile floor. Frequent washing of the floor should take place, and a few gratings with service taps for hose pipes will save a great deal of labour.

Steam Mains.

The engine room must be partitioned off from the boiler house, and the boilers themselves so situated

that the main steam pipes are as short as possible. All lengths should have certain points to which they drain, and the flanges jointed with metallic rings if superheated steam is used, also all auxiliary steam piping in the engine house must be steel pipe, expanded and flanged. Ordinary screw joints may last a few years, but sooner or later they will perish and leak from the action of the superheated steam.

The general arrangement and erection of the steam mains is of great importance, as it is practically the only section of the plant in which it is possible for an explosion to occur. This is due to what is known as 'water hammer.' It is a problem of 'cause and effect.' We know the effect, but the cause is a matter of conjecture.

'Water hammer' is the result of admitting steam into a pipe partly filled with water. It is the action set up by an elastic fluid containing latent heat, when it is suddenly brought in contact with an inelastic fluid.

Undoubtedly much depends on the arrangement of the steam mains. Some, for instance, invite the phenomenon, others tend towards it, while it would be rash to assert that any system exists where it is impossible for it to take place. Even with every safeguard and protection, carelessness and ignorance may in a few minutes bring about the practical destruction of an entire section which has been regarded beyond reproach after years of faultless working. Pressure exerted upon water in a confined space is equally distributed throughout the whole mass, but is able by kinetic energy to exert additional force in the direction of motion. To attain motion its inertia has to be overcome, and on coming to rest its momentum has to be resisted. The more suddenly these operations are performed, the greater is the pressure, and the greater is the resistance

required. Water possesses the quality of minute disintegration, and in commercial practice there is no metal which is not porous under sufficient pressure.

Prevention is better than cure, and there is no reason why with a well-designed system, water hammer should occur if simple precautions are taken. In the first place, as already stated, steam mains should be erected so they drain to certain points, and particular care must be exercised that any section where water can accumulate is provided with a drain of ample proportions besides a corresponding valve for the admission of air. Before permitting steam to pass into the main, these valves must be opened and left open till steam is emitted. However, no expenditure on accessories or automatic devices will avert danger if they are not assiduously attended. The provision of safeguards is worse than useless if they are neither understood nor operated when the occasion arises. In fact, they are speedily reduced to additional dangers in the system. That explosions and disasters are not more frequent is entirely due to the ability and care of those who control the power house.

Accessories.

Most of such items are of extremely doubtful value, and the purchaser should bear in mind that they are made to sell first and economise afterwards.

For instance, before steam traps came into use, steam jackets were efficiently drained by a water sack. When traps are new and in good working order they save attention, but if fixed in situations where superheated system is used they will soon leak. Again, traps must work equally well under pressure or by gravitation. There are also useful devices known as oil separators,

but it must not be assumed they remove *all* the oil in the exhaust steam. Automatic recorders for steam and air pressure and a Venturi meter to register the quantity of discharged air are useful checks.

There are also devices for measuring the feed water, draught in the chimney, and the volume of water circulated through the condenser, etc., and it would be rash to assert that they contribute to the efficiency of the average power house unless they are all carefully looked after and the records kept and compared and, in fact, the condition of a perpetual trial maintained.

On the other hand, an economiser situated in the flue for heating the feed water does effect a large saving. The feed pumps, as a rule, discharge the water from the hot-well tank, which should be above the level of the pump, through the economiser.

These pumps must be suitably proportioned for supplying the average requirements of the boiler. If too large, great difficulty will be found in setting them to run slow enough, especially with water-tube boilers at an air-compressing station, as the demand for them is irregular.

Water Supply.

The importance of an ample water supply of good quality for an air-compressing station cannot be overestimated. Water for the cooling of the air-compressor jackets, for the surface condensers, and cooling the air intakes is required. They can all be supplied from the same pump under normal conditions, but if, for some reason, the condenser is not running and the engine is exhausting to atmosphere, a by-pass from the town service should be provided for the compressor jackets.

The source from which the water is taken will depend

entirely on local conditions; if a river is near at hand, it is obviously the best. If a tube well has to be sunk, make sure the water is not too full of impurities, or heavy expense will be incurred on repairs to boilers, condensers, etc. If it is a necessity to rely on the town supply entirely, a very large cooling pond should be provided. When the cooling water cannot be kept below 90° F., there is, no doubt, a serious loss in the efficiency of the plant.

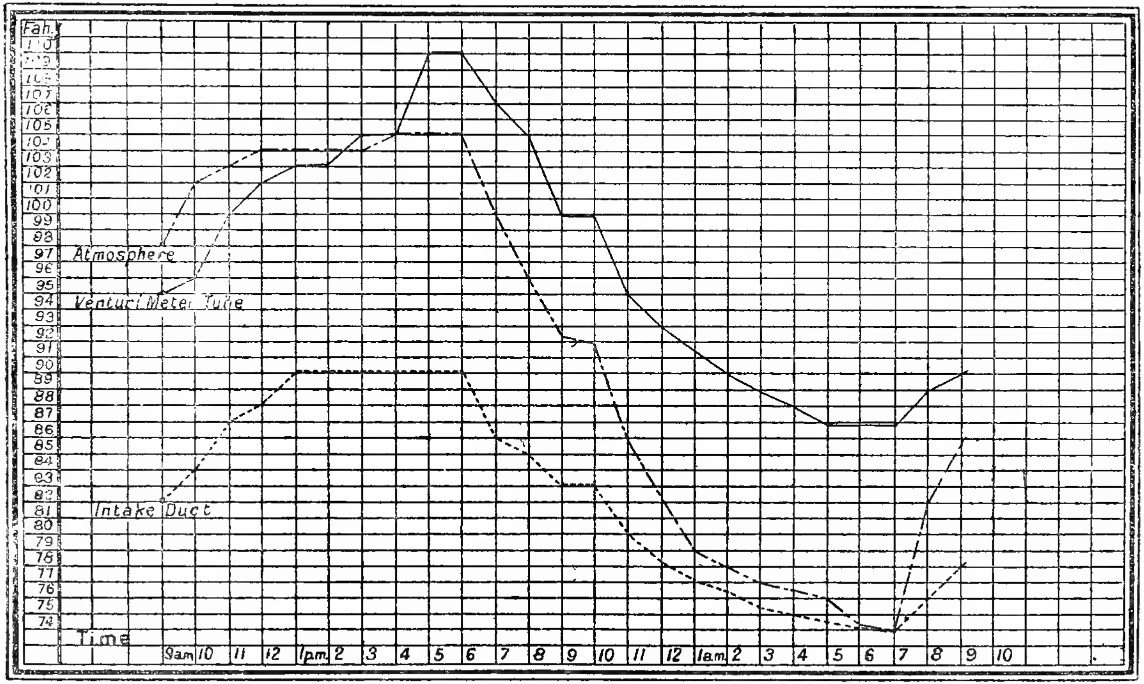
Air Cooler.

In the compression of air, heat is generated, and the more efficient are the arrangements for reducing this temperature the more efficiently is compression carried out. We want to keep the compressor cylinder cool in the same way that we require to keep the steam cylinders hot. With single compressors at low pressure, such as we are dealing with, the loss from this cause can be reduced to a very small percentage: first, from circulating cold water round the compressor cylinder, and secondly from drawing cold air into the cylinders to be compressed. In summer-time and in semi-tropical countries an air-cooling device at the intake is of great value.

It usually consists of a circular masonry well, above ground level, in which roofing tiles are arranged on a suitable frame, and the bell mouth of the intake terminates beneath the tiles. On these tiles water incessantly drips and the air finds its way through the roof. The higher the atmospheric temperature, the higher the evaporation, and the more valuable is the device for cooling the air before being drawn into the compressors. It also effectually prevents dust entering with the air.

Plate XX. shows the difference in temperature of the

PLATE XX



Air Temperature Diagram

atmosphere and the air in the intake duct of the compressor after being cooled. It will be observed that from 4 P.M. to 6 P.M. the atmospheric temperature was 105° F. and in the duct 90° F., a drop of no less than 15° F. With the fall in temperature the difference decreases till at 7 A.M. evaporation ceases.

The temperature in the Venturi meter tube is the temperature of the compressed air before it enters the distributing main. In this case the figure given on the diagram has probably little to do with the temperature at which the air leaves the compressor, as it passes through two large steel receivers exposed to the sun, and the temperature of the air in this receiver which discharges through the Venturi tube depends upon the atmosphere above 90° F.

Volume of Air to Raise Sewage.

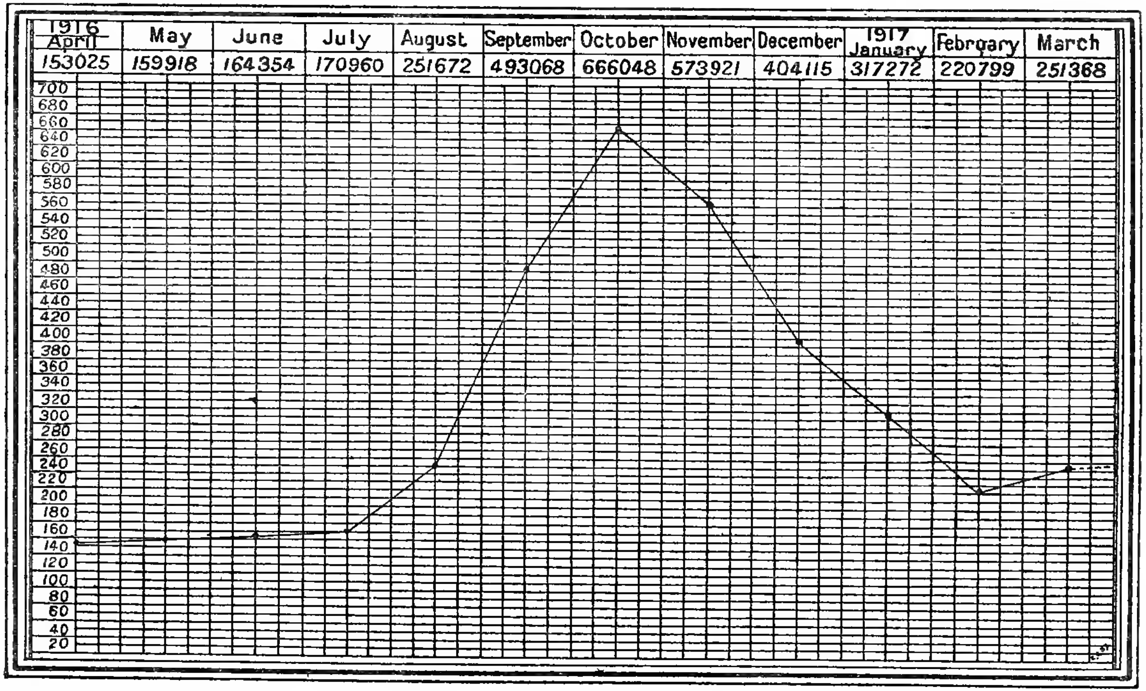
The next six diagrams, Plates XXI.-XXVI., merit very close attention from those who are hesitating between pumps and ejectors on the score of air-main leakage.

The diagrams cover a period of three years and show the volume of sewage raised each month, the air pressure maintained, and the volume of air at that pressure, required to raise one gallon of effluent, by the Cairo Main Drainage Ejector system.

The ejector discharge diagrams, XXI., XXIII., XXV., give the month and year on the first line, the total volume raised in metric tons (cub. metres) per month, and the figures in the left-hand column are 100,000. Thus '980' stands for 980,000 cub. metres, and the lowest figure '300' stands for 300,000 cub. metres, Plate XXV.

The volume of air required to raise a given quantity of

PLATE XXI



Ejector Discharge Diagram

water diagrams, XXII., XXIV., XXVI., show the date and month in the first line, and immediately below each month the volume of air required to raise one gallon. Thus '0·713' = ·713; or nearly three-quarters of a cubic foot of free air is required to raise one gallon of water to a height in feet equal to 22·10 lbs. pressure per square inch. The left-hand column of figures shows fractions of a cubic foot between 0·44 at the bottom and 0·78 at the top, and the upper curve takes its course from these figures.

The lower dotted curve represents lbs. pressure of air per square inch. The bottom line of figures shows the average pressure of air maintained each month, and the right-hand column of figures show fractions of a pound from 20 lbs. at the bottom to 26·8 lbs. at the top.

Thus the top and left-hand column figures (air volume) refer to the upper curve. The bottom and right-hand column of figures (air pressure) refer to the lower dotted curve.

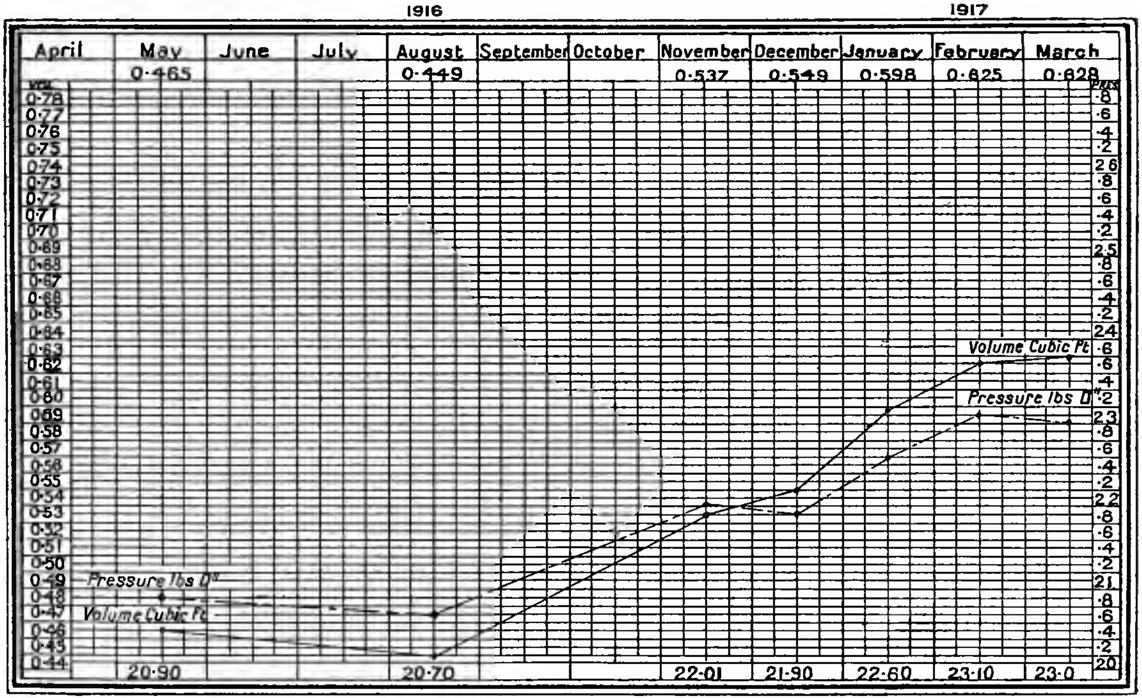
Plates XXI., XXIII., XXV. show the variation of the inflow to the ejector. The great difference between April and October is due to the rising of the Nile, which raises the level of the subsoil water and this percolates into the sewers.[1] The subsoil of Cairo is for the greater part a sandy loam, and any rise in the level of the river is faithfully reflected in the subsoil percolation.

Plates XXII., XXIV., XXVI. show the air pressure and the volume of air in cubic feet to raise one gallon of sewage at a head in feet equal to the pressure given.

In studying the diagrams they must be read together, and what has been previously stated in Chapter III., relative to proportional air-main leakage, will be fully appreciated. That is to say, the greater the volume

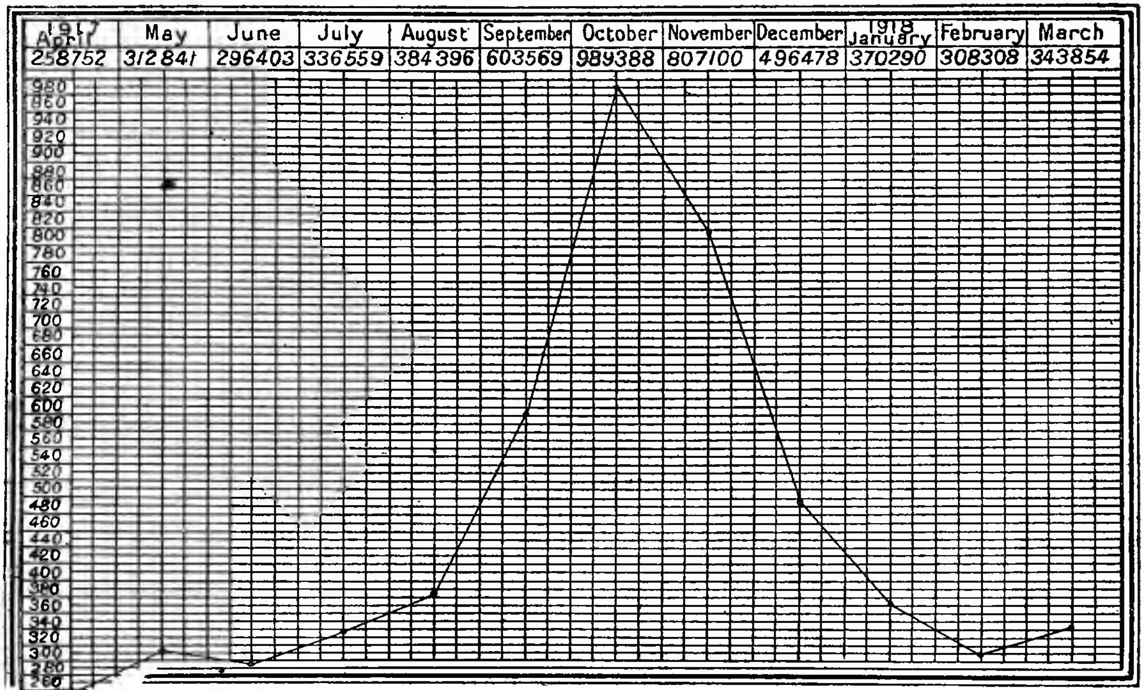
[1] See *Subsoil of Cairo*, by E. C. B. S.

PLATE XXII



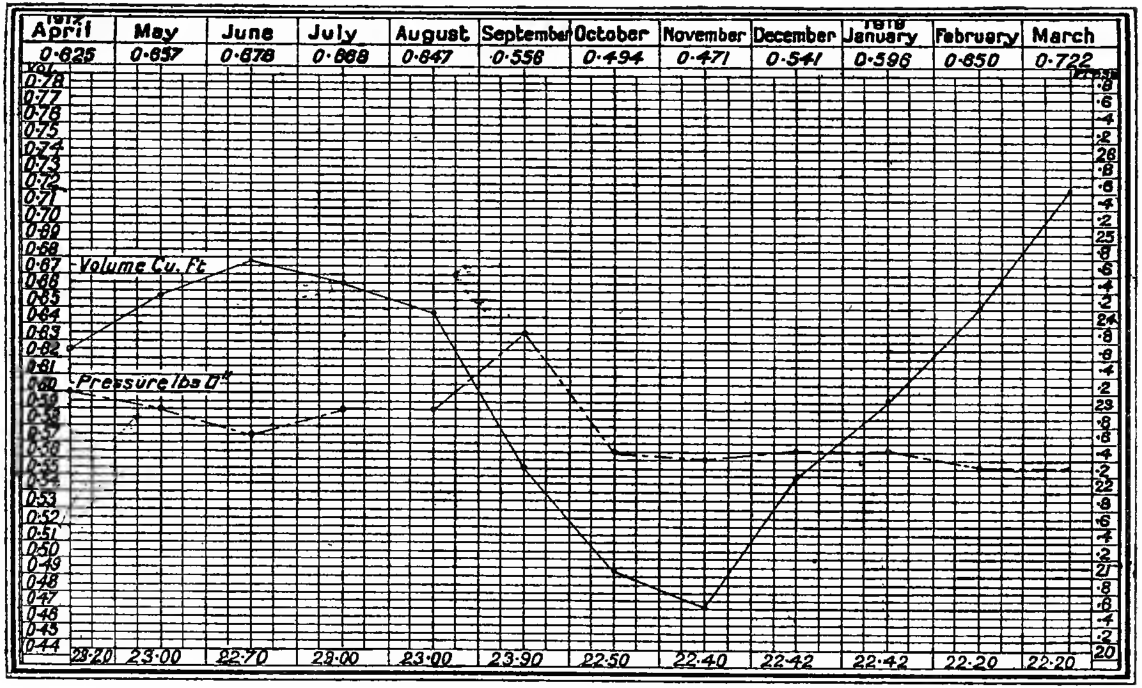
VOLUME OF AIR TO RAISE SEWAGE DIAGRAM

PLATE XXIII



Ejector Discharge Diagram

PLATE XXIV



Volume of Air to Raise Sewage Diagram

raised the less is the proportional leakage, and the lower the air pressure maintained the greater the volume raised for a given quantity of air.

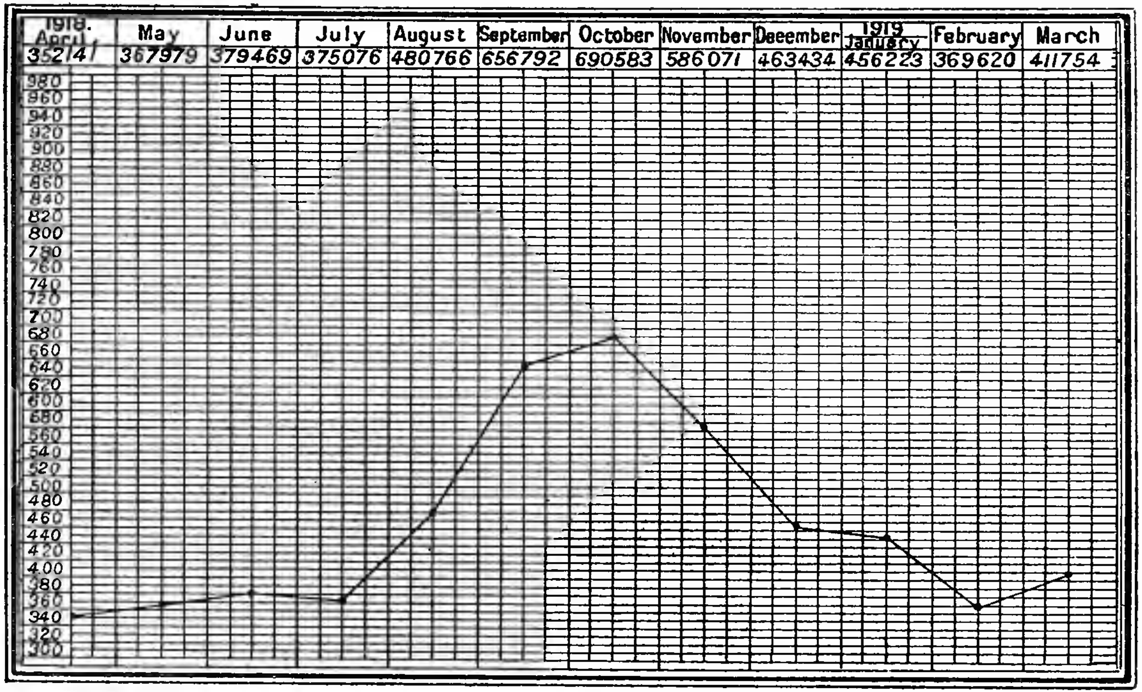
This is beautifully illustrated in Plates XXIII. and XXIV., November 1917. Though October shows the greatest volume raised and took 0·494 cubic feet of free air at 22·5 lbs. to raise one gallon, November shows a better result with 0·471 cubic feet of free air per gallon, as the air pressure was lower at 22·40 lbs. per square inch.

Again, the reduction in volume of air required to raise a given quantity of sewage is well shown in Plate XXVI. for the month of March 1919. In January 1919 (Plate XXVI.) the drop in the volume of air and increased pressure was due to exceptional rain. The air figure is high owing to having maintained 25 lbs. air pressure for several days. If the air pressure had not exceeded 22 lbs., the volume curve would show a much larger drop.

The volume figures for May and August 1916 (Plate XXII.) are the result obtained on official trials. For the month of March 1917 (Plate XXII.) the volume of air required was 0·628 cubic foot, while for March 1919 (Plate XXVI.) it was 0·639 cubic foot to raise one gallon. It is true the volume of water raised is greater, but considering in 1919 air was being used for auxiliary purposes, laboratory work, and burning oil under steam boilers, the increase in leakage from the air main is extremely small. And it must be remembered that during this period practically no opening up or recaulking of the mains had taken place. It is obvious that there is no reason why excessive leakage in an air-main system should exist if the work is carried out under competent supervision.

In cases where a greater volume of water is raised, but

PLATE XXV



EJECTOR DISCHARGE DIAGRAM

the volume of air is also greater instead of less, the extra pressure will account for this result. On the other hand (see Plates XXIII. and XXIV., September 1917), the extra volume of water is so large as to still show a less volume of air per gallon, though an extra pound pressure was maintained.

These diagrams confirm the ejector efficiency curve shown on Plate XII., page 58. They are, indeed, of more value on which to base conclusions than many pages of laboured explanation, multitudes of figures, and all the minute details of an official trial, as we see here *what is actually done in daily work, and not what an installation ought to do.*

Economy in Running Plant.

In running an air-compressing plant for an ejector system with fluctuating conditions of speed and pressure, it is not possible to obtain so high an efficiency as with a pumping engine delivering against a constant head of water.

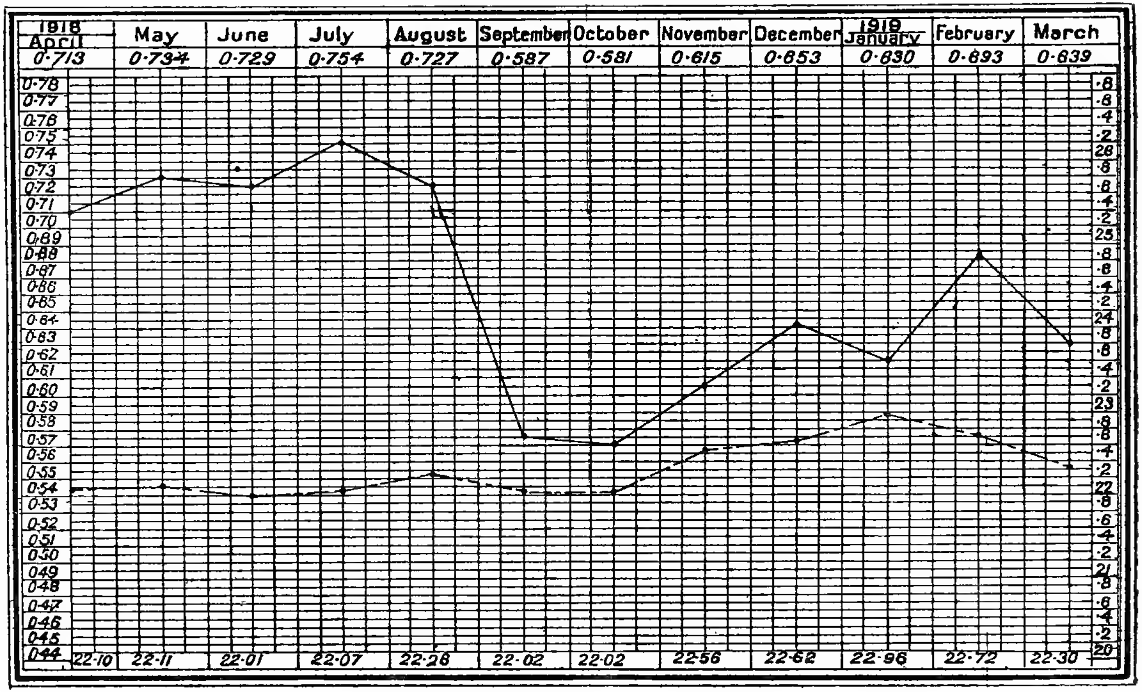
With low pressure and low speed the various forms of automatic governor effect little saving, as the principal loss takes place in firing the boilers to meet a constantly fluctuating demand.

The economy of the plant will depend on the intelligence, ability, and vigilance of the fireman more than any other member of the staff. Assuming he has water-tube boilcrs, the feed pump must be set to give a constant water level, his dampers and ashpit doors adjusted frequently, and only suitable opportunity taken for cleaning his fires.

Fuel.

For the generation of steam we have in order of heating

PLATE XXVI



Volume of Air to Raise Sewage Diagram

value oil firing, coal firing, and rubbish firing. There is also a system of vegetable-refuse firing by first converting it into gas and conveying the gas directly to the furnace. In countries where oil is cheap—that is, fuel oil or residues from the refineries—ordinary boiler furnaces may be adapted to steam or air-jet burners with little trouble and expense.

Though oil firing is practically unknown in England, it is largely used in the East, particularly in many places where ejectors are already installed or could be installed with advantage.

Oil Firing Water-tube Boilers.

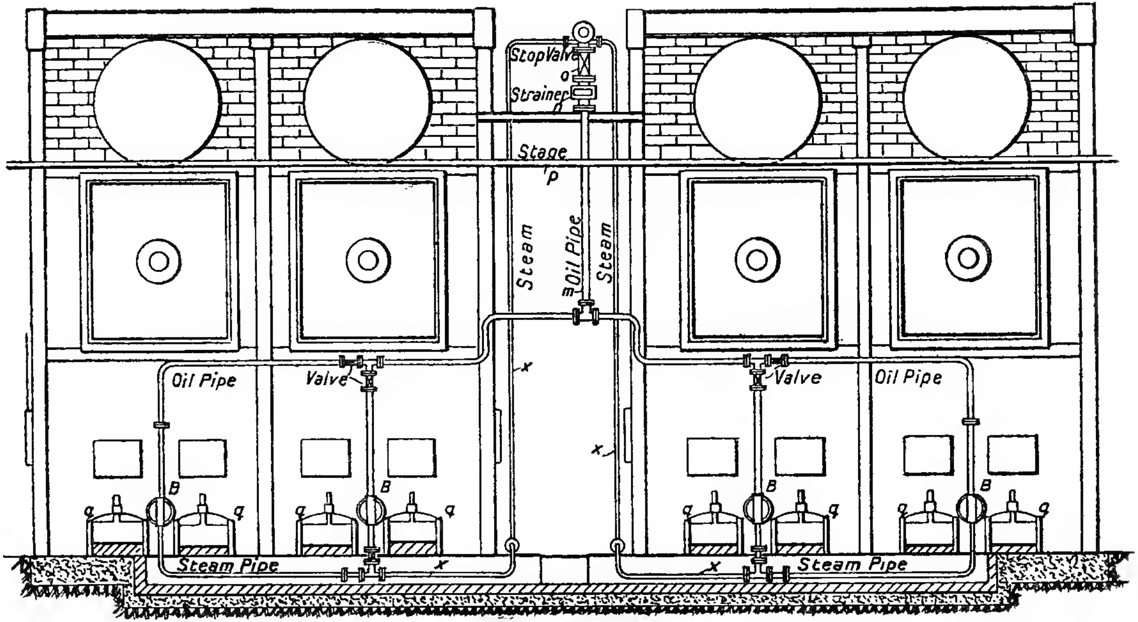
Plates XXVII., XXVIII. show respectively a front elevation and section of a battery of Babcock and Wilcox water-tube boilers of 800 horse-power approx. which have been converted from coal to oil firing. They are used for supplying the Cairo air-compressing engines with steam. Steam is used for the atomising fluid, as though air gives a higher efficiency, the local bricks fail to stand the intense heat. With oil firing it is possible to run two compressing plants from one boiler, whereas with coal this cannot be done.

The position of the ejector, pipes, and feed tank has been arranged with a view to securing the maximum efficiency in working and economy in construction.

The essential features are :

1. Simple and reliable apparatus for raising the oil from the storage tank to the feed heating tank.
2. Arranging the feed tank and all pipework in such a way that all boiler brickwork, flues and economisers, etc., can be rebuilt without interfering with the installation.

PLATE XXVII



Oil-firing Babcock and Wilcox Boiler

3. The efficient heating of the oil, so that the highest temperature is attained as the oil arrives at the boiler.

The oil flows from the storage tank *a* by means of two pipes, controlled by stop valves, to the 50-gallon ejector *d* located in the adjoining chamber *b*, at such a level that the tank can be completely emptied.

The ejector is of the automatic Shone type, operated by compressed air from the main at 22 lbs. the square inch.

The oil passes up the discharge pipe *F* through a stop valve *g* to the feed heating tank *h*, supported on cast-iron pillars, and located in such a position that there is an equal distribution to the four boilers through a minimum length of pipe. This tank is at such a level as to give a suitable velocity to the oil in the feed pipe, and manipulation of the stop valve *o* and interchangeable strainer *n* from the existing boiler stage.

The feed tank contains a steam coil for heating the oil, and a drain pipe *i* carried through the bottom of the tank, controlled by a steam trap *j* for preventing the accumulation of water in the steam coil, and the pipe *k* enables the tank to be emptied of oil, or during use to drain off any water which may accumulate. A suitable float and guide, with pulley attachment and indicator board, is also provided for showing the quantity of oil the tank contains. A distributing plate is also fixed in the tank, beneath the oil inlet, in order to prevent the cold oil from plunging to the bottom.

The steam for heating the coil is taken from a valve cover, or other suitable point on the steam main which is common to all four boilers, and by means of a gland and stuffing-box expansion joint passes through the bend of the oil main.

PLATE XXVIII

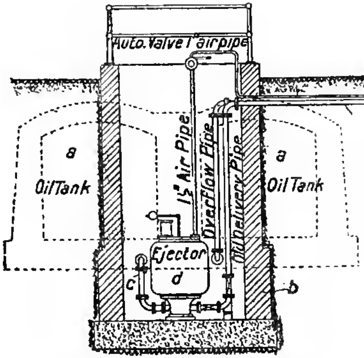


Fig II. Ejector Chamber

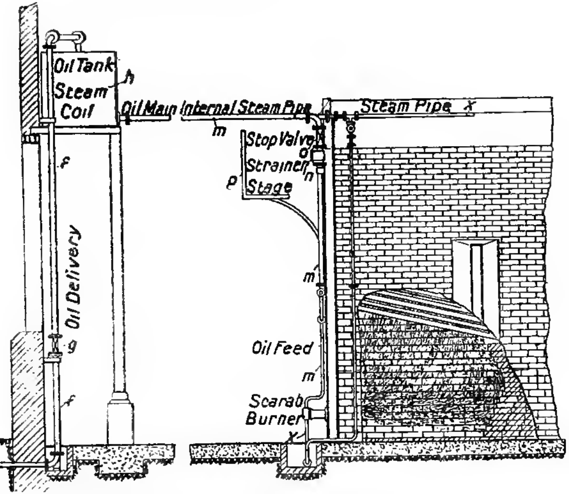


Fig. III. Sectional Elevation

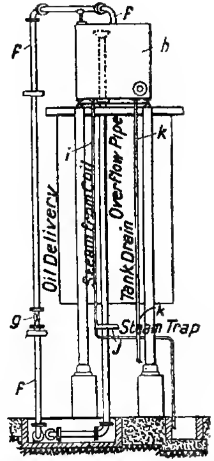


Fig. IV. Elevation on Wall

Oil-firing Babcock and Wilcox Boiler

Immediately below the bend is fixed a strainer controlled by a stop valve, and as the straining medium is attached to the cover of the strainer it can be removed and replaced by a spare cover kept for the purpose while the boiler is working. By this arrangement a single tank and coil is sufficient for four boilers, the duplication of pipes and valves is avoided, and any one of the four boilers can be started up at a few minutes' notice.

Weight for weight there is a saving of 35 per cent. over coal, a saving in transport, and a great saving in labour. Under steady conditions of running such as pumping water under a constant head, the economy of oil firing is more apparent than when applied to an ejector power station.

For the sake of economy in the consumption of air only the minimum pressure is maintained. Compressed air is extremely sensitive to any alteration in pressure, and water-tube boilers are also extremely sensitive under oil firing. The result is we have two highly sensitive powers balanced one against the other, and it requires experience and vigilance on the part of the boiler attendant to keep them in a state of equilibrium.

Though the water-tube boilers may not be quite so economical as the Lancashire type under normal conditions, they lend themselves more readily to the rapid generation of steam in case of rain, which is of first importance. Whether coal or oil firing should be recommended is, of course, purely a matter of the price and supply at which these fuels can be obtained.

Gas Firing.

Owing to the extremely high prices of these fuels that have recently prevailed, boilers fired with gas have

been suggested. Experimental work has shown that it is perfectly feasible, and economical results have been obtained.

The nature of the material is of no consequence. Fallen leaves, straw, sticks, sweepings, and vegetable refuse of all descriptions are fed into a suitable producer, and the gas issues directly to the furnace. To burn such material a large grate area would have to be provided, and difficulty would be experienced in keeping up the steam.

However, when analysing the high efficiencies obtained by this method of steam generation, the capital cost and labour must be carefully taken into account. It takes many tons of vegetable fuel to equal a single ton of oil or even coal, and in place of a single man to attend the boiler we have a number of men engaged in handling the rubbish, and raising it 10 or 12 feet to charge the producers. All such labour must, of course, be deducted from the power of the engine if we wish to compare results.

Fuel oil is the most concentrated form of fuel for firing, and the expenses connected therewith are the smallest. Rubbish firing, whether by dust destructor or by first converting it into gas, is the most laborious, and though the cost of the oil is more by hundreds per cent. the subsidiary expenses and addition to plant for burning rubbish may completely wipe out the difference.

CHAPTER X

IMPROVEMENTS

REASONS FOR INEFFICIENCY.

FROM the preceding chapters it is clear that from whatever point of view pumps and ejectors are considered, the mechanical efficiency of the reciprocating pump is far superior to that of the pneumatic ejector.

On the other hand, the merits of the pneumatic ejector, as an apparatus for raising crude sewage, are so obvious that methods of improving their efficiency are worth some consideration. To spend time and money on obtaining an extra 1 per cent. or 2 per cent. efficiency on the reciprocating pump, when we already have an efficiency of 90 per cent. compared to 40 per cent. of the ejector, is misdirected energy. There is room for very little improvement in the pump, but for a great deal in the pneumatic ejector.

Before discussing possible means of improvement, let us first briefly enumerate the reasons why the ejector is so inefficient from the mechanical point of view. The reasons are as follows :

1. The ejector is operated by a secondary power.
2. There is a certain amount of unavoidable loss in the compression of air.
3. The air is used in the ejector without expansion; there is no 'cut off.'
4. The loss of leakage from air mains.

5. Great variation in the volume of air required.
6. Absence of storage.
7. Fluctuation in pressure.
8. Absence of uniform running conditions.

If there is an average loss of 6 per cent. or 7 per cent. from each of the above causes, it is easy to see that in the aggregate they mount up to a large figure; and again, that the opportunity for leakage and loss is multiplied a hundredfold in such a system as compared to the simple process of direct pumping. Therefore it may be said, as far as the mechanical efficiency is concerned, the ejector will never equal the pump in practice. But that is no reason why we should not endeavour to improve the ejector or accept the low efficiency as a permanent argument against its installation.

It has been clearly shown in raising crude sewage there are other merits of such a nature that they are of equal importance, and as much responsible for the yearly maintenance costs as the mechanical efficiency. Before proceeding, it must be particularly pointed out that the object of improving ejectors is to increase their efficiency without the expenditure of a single additional penny on motive power, and to such an extent that any increased costs in other directions still leave a sufficiently high percentage of improvement to be a commercial proposition.

To be convincing it is necessary to be logical. Therefore we must proceed step by step to show how the efficiency may be improved, and it is as well first of all to touch on some of the elementary aspects of the problem. Let us analyse each cause of loss and ascertain from which it is easiest to eliminate or reduce that loss which takes place, or whether some modification to

the general arrangement of the system or alteration in the running conditions would bring about that desirable end.

Improvements Suggested.

Referring to reasons Nos. 1 and 2, in discussing the merits of a secondary power and the apparatus in which it performs its work, it is difficult to exclude the original source and generation of the prime power, as the conversion of one power to another and its medium of transmission contribute so largely to the ultimate efficiency of the system; and in referring to the efficiency of ejectors we must include the whole system. Thus if the generation of the prime power is inefficient, the loss has to be borne by the apparatus that does the work in the balance sheet of power employed and work done.

By using a secondary power some loss cannot be avoided, no matter what that power is, but the greater the power the less is the loss in proportion. An air compressor is an engine of unevenly distributed resistance. There is loss from clearance, loss from heating of the air during compression, but with a first-class machine and well-cooled cylinders and a pressure of only 20 lbs. and 30 lbs. the loss is exceedingly small, and it is doubtful if there is anything to be gained by experimental work or 'improvements' in this direction.

Compressed Air: Latent Power.

Reason No. 3 offers by far the widest field for improvement and merits some discussion. It is well known the efficiency of compressed air as a secondary motive power, when used in a suitable mechanical apparatus, is little inferior to that of steam. Comparatively speak-

ing, it can be stored. Needless to say, this is a great advantage. It is as well to bear in mind, science tells us, 'the power which is contained in any volume of air at a given pressure is dependent on its distance in temperature above the absolute zero, and that there is as much power in a pound of air at 15 lbs. the square inch (gauge press.) and at 60° F. as there is in one pound of air at 100 lbs. the square inch (gauge press.) and at 60° F.' But, of course, the energy available for useful work is much greater in the higher pressure.

Again, as to the application of compressed air to ejectors: 'The volume of one pound of air at 30 lbs. the square inch (gauge press.) and at 80° F. equals 4·412 cubic feet, and the greatest amount of work it can do in an ejector is 19,060 foot-lbs. But the same quantity of air under adiabatic expansion could yield 27,405 foot-lbs.' The significance of this cannot be overstated and must not be lost sight of.

Compounding Ejectors.

To re-use the air in the ejector, or use it expansively would, without doubt, be a great improvement. In the compound steam engine the motive power, after performing work in one cylinder, is admitted to another of greater volume, in which it continues to do useful work till nearly the whole of the available pressure is extracted from the steam. The motive power is directly re-used in the engine, with the result that a degree of economy is attained which is quite unknown in the pneumatic ejector. By duplicating the cylinders and reciprocating parts we practically double the useful work performed in the conversion of steam to mechanical power, the reciprocating parts and the flywheel (if there happens to be one) by means of kinetic energy largely contribut-

ing to this result. But in dealing with a liquid it is particularly difficult to make the fullest use of the expansive power of the motive fluid as an even pressure has to be maintained throughout the stroke by the steam, if we do not provide some type of compensating attachment for the storage of the energy used in the motive cylinder.

As already stated, the ejector has neither rotary nor reciprocating parts; the motive power is the piston or impeller. The ejector will admit and discharge sticks, stones, bags, bottles, metal, rubbish and solid matter of every description continually without injury, and requires no screening of the sewage. To introduce rotary or reciprocating parts to an ejector or bring them in contact with the liquid at once destroys the utility and perfection of the apparatus. Hence we cannot store the energy of the motive fluid and use it expansively by the usual methods. In compressed air we are using an ideal motive power. In fact, we have at our disposal a gas, elastic and non-explosive, and theoretically, according to science, capable of giving out as much work as is expended upon it. Yet with this remarkable motive fluid we find the pneumatic ejector in the lowest ranks of mechanical efficiency—principally for this reason: the immense expansive power, the latent force, the intrinsic energy of the air itself, is absolutely wasted.

In fact, as far as motive power is concerned for discharging the ejector, we might as well be using water, a solid 'dead power' which is dependent on kinetic energy alone without latent power. The discharging of the effluent from the ejector, as before remarked, is the work the compressed air has to do, and it is obvious from the construction of the apparatus that the volume of air must be maintained throughout the whole of this opera-

tion at a certain pressure to raise the water to the required height.

Exhaust: Waste of Power.

Therefore it follows that at the end of the discharge a volume of compressed air at full pressure fills the body of the ejector in place of the liquid expelled. The exhaust valve opens and the whole of this 'power' is discharged into the atmosphere without restraint, a power equal to the entire energy of the motive fluid being treated as a mere 'waste product' of the machine.

It is indeed the liberation of a mechanical agent under full control, from which we have neither extracted the energy nor reduced its capabilities for further work.

It is this 'waste product,' the exhaust from the ejector, that it is possible to make use of either by using it as a motive power for recompressing a certain percentage of its own volume to assist the next discharge, or returning the exhaust to the power house and recompressing the air. For the exhaust air to recompress a percentage of its own volume to assist the next discharge would be the most economical in a multiple ejector system, but at the lower pressures the motors would have to be an unwieldy size. The distinctive characteristics of such a motor are: the pressure air flows through the engine when the pressure falls below a predetermined value, and that upon the pressure rising above such a value the necessary exhaust ports are closed and the engine started; a rotary cam shaft to which is automatically imparted a lateral motion by means of a spring-controlled piston and cylinder, operated by the motive fluid, which drives the engine for the purpose of starting and stopping the motor.

The air and exhaust valves of an ejector installation

owe their reliability to what is known as 'pneumatic control.' Comparatively speaking, there is nothing to wear out and nothing to go wrong. No levers, no links, no pins, a few lengths of small tubing and the thing is done how and where we like. Needless to say it is a simple matter to adapt such a system to control the air motor compressor in such a manner as to make it as automatic in action as the ejectors themselves, and at the same time safeguard their own continuous working.

The principal characteristics of such a system of control are: the application of a valve, termed the differential exhaust valve, which is capable of taking up one of two positions for the purpose of arresting the discharge of the exhaust directly to the atmosphere; the application of a valve, termed the intercepting valve, to either ejector for the purpose of delaying the action of the differential exhaust, to enable one ejector to be discharging while the other is exhausting to the motor compressor, an arrangement of operating pipes which enables the action of the above valves to be entirely controlled by the rise and fall of the liquid in the ejector body.

It must not be supposed that it would be worth while compounding ejectors by such means at every ejector station in a large system, as in many cases small ejectors will not discharge more than a few thousand gallons per day, and the cost of the air saved would not equal the extra expenditure and maintenance. In large stations, however, discharging half a million gallons per day and upwards at a pressure of not less than 25 lbs. the square inch, a real increase in efficiency would undoubtedly be effected without additional expenditure in motive power. The higher the pressure the greater the value of utilising the exhaust air, and there appears to be no reason why any

pressure up to single compression, say 60 to 70 lbs. the square inch, should not be used economically by such means for raising crude sewage. Such an increase in pressure would bring the ejector within range of the majority of sewage schemes.

Objections to Compounding Ejectors.

Objections have been raised against using the body of the ejector as an air receiver, as it prevents the ejector from being used at the maximum capacity in abnormal times, such as heavy floods. With the simple ejector, the exhaust opens, the air escapes at once, and the water fills the ejector against the atmosphere at the maximum rate permissible by the size of the inlet pipes. If the ejector is used as a receiver, the water would only fill the ejector as the air pressure was reduced—that is to say, the action of the ejector would be delayed half a minute or other predetermined time. Therefore in time of flood if the maximum rate of working was required under such conditions, the 'capacity' of the ejector station would be reduced—in other words, would not be able to deal with so large a volume of water in a given time. But in the application of the differential exhaust valve mentioned above, provision has been made so that the ejector can return to simple working at any desired moment and the full capacity made use of. In normal times the average ejector does not work at more than half its capacity. In fact, whether it is a pump or an ejector, a large reserve must always be provided in raising sewage.

Within recent years motors and turbines of all descriptions have been brought to a high state of perfection, and what would have been an 'extravagant proposition' ten or fifteen years ago is now regarded as everyday practice.

To utilise compressed air in turbines or motors, a much more expensive class of machinery is required than for an ejector, but if the gain in efficiency is of sufficient magnitude there is no reason why the exhaust should not be used. No doubt the exhaust would have to pass through a filter, but the grease and grit now carried up by the sudden release of the air would be absent under steady conditions.

As a rule, ejectors are in the hands of corporations and municipalities. They are completely out of sight and from one year to another their existence is unknown, except to the man who attends them. There is no incentive to improvement as long as they perform their work, as their maintenance is paid for by the ratepayers, and the rate for sewerage is looked upon as an unavoidable burden which cannot be reduced. But of recent years the ejector has been adopted by many firms for draining large factories, and there is little doubt that those who have had actual experience of their working are fully alive to their great merits compared to low-lift pumps which would otherwise be installed for such purposes.

Recompressing the Exhaust.

There is another method of recompressing the exhaust from the ejector, by returning the air to the power house. Provided there is only a short length of exhaust main from the ejector to the power house, this is an admirable plan, and has given some excellent results in practice; but the writer is not aware that it has been tried on an extensive scale. Indeed, an efficiency of 64 per cent. has been claimed under suitable conditions. There seems to be no reason why such a system should not be applied to a large super-ejector station, when there

are no air mains, and even higher efficiency obtained. With a multiple system, however, scattered over a large area, the extra expense of duplicate mains would be a heavy item in first cost, and the maintenance of the air mains would be doubled. It is, though, just one of those improvements that can be applied in certain localities that is worth careful consideration.

It must not be forgotten that the larger the station is—that is, the greater the power employed—the better are the results, and those who only judge efficiencies from experience with small powers are working at a disadvantage.

Of all power schemes an ejector system is probably the most unsuitable to obtain a high mechanical efficiency, owing to the comparatively intermittent nature of the work and the small power employed.

Expansion of Air in the Ejector.

A third way of improving the efficiency of the ejector is by using the air expansively in the ejector body—that is, by applying a valve to cut off the air when a certain volume has passed into the ejector. Probably more time and money have been expended in attempting improvements in this direction than in any other. It entails the smallest capital outlay and would be a direct saving.

The end in view—expansive working of the motive fluid—is most desirable, but the means of carrying it out are subject to certain difficulties. It is just one of those improvements in which we may lose more in one direction than we gain towards the end we are trying to attain. To use the air expansively it must be admitted to the ejector at a higher pressure than is required to overcome the actual head plus friction. To do this more

work is required from the compressor at the power house. Either some form of cut-off valve or compensating device must be employed for the storage of the excess power. But, like the direct-acting simple pump, a certain pressure must be maintained throughout the stroke or discharge.

In the case of the ejector, if the pressure falls below that figure it will not empty, the weight will not fall, and the exhaust will not open. Neither will the ejector refill as the exhaust cannot escape. Unless we have a higher initial pressure it is difficult to see how expansive working can be carried out, but if we have this higher pressure beyond that actually required to raise the effluent, there is at once the additional loss in compression and leakage from the air mains. It is true that when ejectors discharge through long mains the last 25 per cent. of the discharge is assisted by the kinetic energy of the liquid, but to utilise this for expansive working of the air would need precise calculations and a uniform pressure for each discharge.

A smaller volume of high-pressure air, admitted to the ejector and cut-off, will, no doubt, do the work by expanding, provided there is no leakage whatever from the exhaust, and the pressure in the ejector does not fall below that figure required to overcome the total head on the rising main. However, in dealing with low pressure a cut-off valve must be extremely accurate and air-tight to effect such a purpose.

The pneumatic control of the ejector is simple, efficient, and reliable, as it consists of piston valves which are required to take up one or two positions only irrespective of pressure and cut-off, and they are firmly held in position by air pressure. Moderate leakage does not affect their working, but in a cut-off valve that is to

admit a certain volume only, any leakage from that said volume and the air will fail to displace the liquid. Again, the air pressure in the main must not vary as the volume of air admitted would vary.

In certain respects there is no secondary power or motive fluid so easy to control or reliable in operation, but it is extremely sensitive to any leakage, and easily loses its power. The merits of compressed air as a fluid power must be mastered, and its limits carefully borne in mind when it is used for actuating mechanical devices.

The Loss from Air Mains.

Reason No. 4. The loss by leakage from the air mains is in the opinion of many engineers one of the greatest objections to the ejector system. A great deal depends on how the air mains are laid, in the first place. With efficient supervision the leakage will be small in after years. To reduce the expenses from air-main loss there are three ways :

1. Recaulking the pipes.
2. Doing away with the pipes.
3. Selling the air for other purposes.

Recaulking the joints and keeping the valves in a good state of repair is an elementary but none the less most efficient remedy. In ejector systems there is a certain point beyond which it would not pay to go. With air at only 20 and 30 lbs. the square inch, it is quite feasible to keep within a 5 per cent. leakage ; but whether it would cost more in repairs than the value of the air lost much below this figure is open to question. If the pipes have been well laid, joints well run, and no short lengths permitted, it is a simple matter as no re-running is required and the position of each joint can be marked off from

the surface. On the other hand, if careless work has been the practice during construction, pipe spigots, butted against pipe sockets with no room for running lead, and indiscriminate laying of short lengths of pipe, the joints cannot be located, and yards of pipe will have to be relaid to recaulk a single joint in a satisfactory manner.

It is not only the pipe joints but the stop valves that must be tight, or testing lengths of pipe to locate leakage cannot be carried out. It is possible to put down cast-iron flanged pipes or steel pipes with flanges suitably attached, if the additional capital expense is not objected to. In busy streets, where traffic is very heavy and it is worth while avoiding the inconvenience of a single recaulking after the pipe has once been put down, the extra cost may be justified, but it must be remembered in many soils the life of the steel pipe may be a disappointment.

The ordinary cast-iron spigot and socket pipe has great merits for street work. It is easy to cut to any desired length, bends can be placed just where they are wanted, and the flexibility of the joints permits of considerable deviation from the straight line which it is often impossible to keep to owing to existing water pipes, valve chambers, and many other such obstructions. It is the cheapest to put down, simplest to joint, the most adaptable to varying conditions, and easily repaired. With reasonable care and a very moderate outlay on maintenance, the loss to an ejector system from this cause can be kept down to a small figure. The loss by leakage from the air main is the simplest to remedy, but in many cases it is permitted to be the greatest, even running up to 20 per cent. and 30 per cent. The greater the volume of air transmitted by the mains the

less is the proportional loss by leakage, and the less is the upkeep per 1000 cubic feet of air compressed.

It must not be supposed from these remarks that cast-iron spigot and socket pipes constantly want repairing; on the contrary, when the joints are well run, well caulked, and the pipes well bedded, there is practically no limit to the time they will remain air-tight.

For an ejector system laid out under the average conditions, it is doubtful if there is any improvement to be made in the means of transmission over the spigot and socket pipe for the same expenditure.

Electric Transmission.

Suggestions are not infrequently made that the air mains should be done away with in order to avoid leakage. No doubt this would be a most effective method; but it is a question whether the remedy may not be more inefficient than the evil. It has been proposed, if not actually given a trial, to have a multiple ejector system with a central power station for the generation of electricity, which is transmitted to the ejector station by cables for the purpose of supplying motors for driving small air compressors at each of the ejector stations. To introduce a third power of a necessity adds further complications and losses in other directions.

Whether we use internal-combustion engines or steam engines, it is the first essential to economy to generate power in bulk, and every time we convert one power into another there is a certain amount of loss. The smaller the power unit, the greater the loss from friction and less the efficiency. If we have a multiple ejector system of fifty stations, it is not only a question of how much we should lose from friction and inefficiency, compared to the loss from the air main, but the additional

risk from failure by the introduction of further mechanical motion between the secondary power and the work to be done. It means the addition of two motive power engines between the prime power and the work it has to do. Between electric cables and cast-iron pipes the difference in cost is not great, so the motor and compressor would be extra cost without compensation, and there is no reason to suppose that the mechanical efficiency of fifty small air compressors could even approach that of a single large unit. Again, in order to cope with the maximum discharge from the ejector, the compressing unit would either have to be in duplicate or of large size, and such units would give poor results under normal conditions existing ninety-nine days out of a hundred. That more supervision would be required is a certainty, and the repairs to an ejector station which now amount to 'shillings a year' would be multiplied a hundredfold. Presumably the compressors would be water cooled, and a water supply would be required for each station.

Other items of expense could also be enumerated, but there is no object in pursuing this method further, to show that the initial cost, maintenance, and efficiency would be no improvement over a single power station for compressing the air in bulk and distributing it to the ejector stations by means of cast-iron spigot and socket pipes.

Selling Compressed Air.

The idea of reducing the loss (expense) by leakage from the air mains by 'selling the air' may seem at first 'far fetched,' but this is by no means the case. If only a proportion of the air is sold it will assist to make a compressed-air system self-supporting in place of an unremunerative burden on the ratepayers. Care

would be substituted for neglect, as it is now only too often not considered worth the expense to maintain air mains in a high state of efficiency. Money spent on maintenance would be money saved on the system, in a sense which is not now realised. The greater the output of air the greater the efficiency of boilers, engine, and compressors. If the power station is converted from a dead loss into a self-supporting scheme, the whole aspect of a compressed-air drainage system changes. Even if the rate charged for the air was only sufficient to meet the actual expense of that volume sold, the air that is not sold but used by the ejectors is produced at a *cheaper rate* as the total volume compressed is greater, the proportional leakage is less, and it would be worth while to reduce that leakage to a minimum.

Uses of Compressed Air.

Compressed air at low pressure, 20 to 40 lbs., is an absurdly cheap power when generated in bulk and distributed as a secondary power; it is absolutely safe and easy to handle, and in some cities it can be used extensively as the atomising agent for burning liquid fuel, especially for domestic purposes and firing the kitchen range. Air hoists, pneumatic despatch, and raising water to the top of high buildings are also purposes for which it possesses exceptional merits. Incidentally, it may be remarked the war has been responsible for the use of compressed air for culinary purposes.

Compressed Air for Domestic Oil Firing.

Cheap firing is a necessity to civilisation, but in many Eastern cities the price of coal has increased so enormously as to make it more economical to burn fuel oil,

but it cannot be used economically and efficaciously in the kitchen range without a small volume of compressed air for atomising purposes. In coal-producing countries it is not likely that oil will be extensively used as a substitute ; but there are many cities in the East, such as Cairo, Bombay, and Rangoon, where compressed-air systems already exist. Indeed the compressed-air Cairo main drainage system has been successfully used for firing kitchen ranges for the last twelve months. The average pressure in use for ejector systems is very suitable—that is, between 20 lbs. and 30 lbs. the square inch—as this is sufficient for atomising the heaviest fuel oils (residues), which are the cheapest.

The combustion of fuel oil in the kitchen range by means of compressed air shows a saving of 50 per cent. over coal, weight for weight, and in all cities where fuel oil can be obtained at not more than double the price of coal there is little doubt there is an extensive field for its use in combination with a pneumatic-ejector system for draining the city.

As pointed out in preceding chapters, the commercial efficiency of a compressed-air system for draining level districts is by no means inferior to that of pumps, and it possesses many exclusive merits, which engineers readily admit, but the cost of the power house and maintenance has made many authorities hesitate to adopt it. If, however, a percentage of the air can be sold and the output of the power house increased, the costs are at once reduced, even if the sale of the air is not on such a large scale as to make the system self-supporting.

Though hand power will light a liquid-fuel burner for the kitchen range, as the volume of air required is so small, it cannot compete in cost with the generation of

power in bulk, and the greater the volume the cheaper the air.

There is no reason why compressed air should not be supplied to city populations for combustion purposes in the kitchen range in the same way as water, gas, or electric light. If it pays a man to light his house from a power station, how much more will it pay him to cook his dinner when the power costs but a fraction of that from which he derives his light.

There was a time when laying a gas pipe to the smallest rentpayer in a city, for the purpose of providing light, was ridiculed, and it is not so long ago that electric light was regarded as a luxury for the rich and an advertisement for up-to-date theatres.

But the novelty of to-day is the accepted necessity of to-morrow, and these means of illumination are as much a part of our daily lives as the electric tram and motor bus of every large city.

Cost of Compressing Air.

As previously remarked, compressed air is an absurdly cheap secondary power at low pressure, and a few remarks concerning the cost will be of interest, together with how much air such burners consume, as if these pages should meet the eye of municipal engineers with compressed-air systems under their supervision they will be able to form some idea of how much their maintenance costs would be reduced by the sale of the air.

The fuel cost of compressing air to 100 lbs. the square inch with Diesel oil engines is claimed to be as low as $1\frac{1}{4}$d. per 1000 cub. ft. of free air. This may be exceptional, but it is obvious that with a pressure of only 30 lbs. the square inch, 1d. per 1000 cub. ft. will cover the cost under the same conditions.

However, it is better to base calculations on actual records, poor though they may be, than on possible performances, and the figures now given are of exceptional interest.

The Cairo compressed-air system is a large one, comprising four sets of triple expansion, steam, air-compressing engines, and each engine is capable of compressing 2,000,000 cub. ft. of free air per day of twenty-four hours at a pressure of 22 lbs. the square inch, which gives a working pressure of 20 lbs. the square inch in distant localities.

For the year 1916-1917 the volume of free air compressed was 573,240,000 cub. ft. at a total maintenance cost, including fuel, of £E.6878·900, which equals a cost of 3d. per 1000 cub. ft. of free air compressed. It must be understood that this is anything but economical, but for our purpose it is sufficient.

In the present state of the sewage scheme there is ample reserve power, but in cases where there is not, an extra compressor can be put down, and by slightly raising the pressure when abnormal conditions arise existing mains will prove of sufficient capacity.

Consumption of Air for Liquid-fuel Burners.

The consumption of air by a kitchen-range burner varies from 0·119 to 0·50 cub. ft. free air per minute, according to the size of the range and extent of the cooking. Taking an average figure of 0·30 cub. ft. per minute, this equals 18 cub. ft. per hour, or 216 cub. ft. per day of twelve hours or 78,840 cub. ft. per year, at a cost of just under £E.1·000 (one pound). Allowing for leakage, depreciation, sinking fund, and interest, together with supervision of reticulation, a charge of £E.2·000 per year per burner should leave a good profit. Now 2,000,000 cub. ft. of free air at 20 lbs. pressure will supply 9259 domestic

fuel burners, which at a charge of £E.2·000 per year each would produce a sum of £E.18,518·000.

The figures given are Egyptian pounds, which are worth 6d. more than the English pound; this makes no difference for the purpose of an estimate, and it is easy to see that a sum of £18,500 will go a long way to make a power station self-supporting that is supplying, say, 2,000,000 cub. ft. of air a day for drainage and 2,000,000 cub. ft. a day for remunerative purposes.

All large consumers would be charged by air meter, and precautions taken that no householder should be able to obtain more than his share.

Ordinary lead piping, such as used for water and gas, is quite suitable for laying the air on to the houses and, being jointless, no leakage need be feared.

Cost of Oil Firing with Compressed Air.

From the consumer's point of view there is no question that the supplying of compressed air from a central power house is by far the cheapest and most reliable, and in oil-producing or oil-burning cities it is the means of placing cheap firing at his disposal. Previous to the war £2, 10s. per ton for fuel oil was not unusual, and much less in some Eastern towns. Experience shows that the domestic range consumes from 2 lbs. to 9 lbs. of oil per hour, according to the size of the range and amount of cooking.

In the average household 4½ lbs. of oil per hour would probably be sufficient for seven hours a day. This equals 31 lbs. approx. of oil per day at a yearly cost of about £12, 10s. or, plus the compressed air, £14, 10s. To compete with this figure coal must not exceed 27s. per ton.

The supervision of a 300 horse-power plant costs as

much as the supervision of a 600 horse-power plant, and the cost of the fuel diminishes in proportion with the greater power. In an air-main system, when all the mains are in use, the loss by leakage is precisely the same whether 8000 cub. ft. or 8,000,000 cub. ft. of air are being used per day; but the smaller the volume used the greater the proportional loss, and the greater the volume used the less the proportional loss. Therefore the greater the consumption of air the higher is the efficiency of the installation.

If the compressed air from a pneumatic ejector power house can be sold for domestic and industrial purposes, we are much more likely to increase the efficiency of the system by making full use of the air mains than by doing away with them. That there are improvements to be carried out in the use of compressed air which will increase the efficiency of the system, there can be little doubt.

Air Storage.

Reasons 5 and 6. The great variation in the volume of air required in the twenty-four hours is a cause of inefficiency.

To store the air would appear to be the obvious remedy, but at the low pressure used this would need receivers of impossible dimensions. To store the air there is little doubt the pressure would have to be raised considerably, and to raise the pressure we should at once decrease the efficiency of the air compressor. In small schemes comprising two or three small ejector stations, storage is quite feasible for one or two hours, but as soon as we come to large powers there is little doubt it is more satisfactory and economical to keep the engine running.

In large plants many other factors besides the compressed air have to be taken into account in stopping and starting up the machinery. In most cities, especially dry countries, the flow of sewage is regular, but the variation is great, according to the hour of the day. From 1 A.M. to 4 A.M. the flow will be at its minimum, whereas from 7 A.M. to 12 P.M. three or four times as much power may have to be provided for. The flow is gradually rising or gradually falling at most hours of the twenty-four. It is from this fact, more than all else, that makes it so difficult to obtain the economy one would expect by installing internal-combustion engines in place of steam engines. By careful regulation, a steam engine that will give the maximum daily output required can be run dead slow to suit the minimum flow; but with the internal-combustion engine a certain speed is essential, and the surplus air has to be blown to waste or some automatic device provided for cutting out the compressors while the engine is running.

This reason of inefficiency is inherent to the ejector system. It could be done away with by storing the sewage, but to do this we should at once destroy one of the outstanding merits of the ejector. Automatic regulation from the air pressure has so far not proved very successful, and as the real fault is the direct result of performing the work to be done in an efficient manner, from another point of view, other than mechanical, it is a case of one efficiency having to give way to another. Such being the case, the most effective improvement is the extension of the use of compressed air, as the larger the volume required the less would be the loss.

Reasons of Fluctuation in Air Pressure: Remedies.

Reasons 7 and 8 may be taken together. There is probably no class of power system in which there is such an absence of uniform running conditions and constant fluctuation in pressure, especially compared to a pumping plant.

As the volume of air required is always rising or falling, the driver must be constantly adjusting his engines, and the fireman attending to the dampers, furnace, and feed water of his boiler. He should, of course, anticipate the demands to be made on the boiler, but this is exactly what he is not able to do. The first intimation the fireman receives of a demand for more steam is a falling gauge, as the driver in the engine house has opened the steam valve to increase the speed of the engine, to make good a falling air pressure. Possibly it is opened a shade in excess of what is required or not enough. The fireman has no idea if he will have further demands on the boiler in the next five minutes, or whether it will be blowing off steam. If he is pressed for steam he probably reduces the feed and brings the water down an inch or so in the glass, then when he eventually fills up again there is a further fluctuation in pressure, and it is a rare thing to get more than a few hours' steady run in the twenty-four. It must be remembered the fluctuations in running a boiler are just as detrimental to efficiency as fluctuations in the engine, and their steadiness depends on the uniform conditions of the work to be done.

Compressed air is similar to a spring under tension, and if we can imagine a pressure at one end of the spring and a variable resistance at the other, it is easy to understand that as the resistance alters so must

the pressure, if the spring is to be kept at the same tension.

Similar conditions are not unknown in mechanical practice, and an equilibrium between the power and the work is usually maintained by an accumulator, in which surplus energy is stored, thus permitting a uniform speed of the engine compressing the air.

To improve the efficiency of an ejector system by such means we should require an apparatus on the same lines. Air receivers of considerable capacity are already part of the plant, and there seems to be no reason why an overhead water reservoir at a suitable height to correspond with the required head, and of a capacity to suit the receivers, should not be provided, and the necessary connections arranged. This would have the effect of steadying the pressure against which the engine is running. It would fulfil the same purpose as that of a stand pipe on a pumping installation.

Assuming the engine is running at 100 revolutions per minute at a steady pressure of 22 lbs. the square inch, this is what occurs : a sudden demand for air above the normal is made at one of the large ejector stations. Instead of the pressure falling, the water from the overhead reservoir runs into the air receivers and displaces a volume of air in addition to the constant flow from the engines. The driver will see from the level of the water if the demand is temporary or continuous. If necessary he increases the speed of his engine and the volume of water that has displaced the air is forced back into the reservoir when the demand is again normal, or if the demand for extra air soon ceases there may be no alteration of the speed, the normal discharge of air being sufficient to keep the water out of the air receiver.

By this means it is possible to run the boilers and

engines against a constant pressure ; the efficiency would be improved, as the running conditions would be more uniform.

When engines are running under normal conditions at almost, if not quite, their maximum speed, there is very little doubt considerable saving by such means would be effected, as it is on such occasions that the pressure cannot be prevented from falling, and there is always some hesitation as to whether it is worth while starting up reserve engines to recover a pound pressure.

Improvements Defined.

This chapter is headed 'improvements.' Few realise the true meaning of this word, and fewer still are those who are able to initiate and carry them out. The mere substitution of one power for another does not come under the heading, as the most economical type of power unit is invariably decided by local conditions. A real improvement is actually saving or re-using a percentage of the power generated, without the additional expenditure on maintenance being of such magnitude, as to exceed the cost of the power saved, or again the improvement of some mechanical detail which saves power, labour, and expense.

To accomplish this requires long experience and an exhaustive study of the power and the work it is doing, together with resource, self-reliance, and wisdom. The generation and application of power is the interpretation of physical science.

All science starts from a common basis—that is, fact and reason—and there is nothing more remarkable how true thinkers, and those who have mastered their profession, in theory and practice, proceed on the same lines of thought to solve original problems that tend to

improve efficiency and utilise the means at our disposal to the best advantage.

The nature of the problem is of little consequence, as there is a sympathy of mind and method which is entirely absent to the superficial intellect. We must strive for perfection in practice and utilise experience, besides possessing scientific ability, as the one without the other is a superficial knowledge of the subject whatever it may be.

Practice unassisted by science is crude and clumsy, restricted to narrow limits and elementary tasks, but theoretical science alone is a negligible quantity, as we cannot use an abstract faculty independent of action. A superficial knowledge of physiological, theoretical, and material things is the baneful curse of daily practice. To master a power problem, the driving force, the bed-rock on which it is founded, must be analysed and examined, and the why and wherefore of actual facts of scientific laws ineffably impressed upon the mind from daily experience.

It is the secret of resource and self-reliance.

It is better by far to excel in one direction than to be content with superficial attainments, for the simple reason the power to excel in one direction gives us the power to excel in others. Every engineer, every individual possesses some gift or latent ability that is capable of being more highly developed than others. Foster it, encourage it. It is in the application of such gifts that he will benefit the profession and rise out of the conventional rut of repetition work.

Practise that particular bent in which the inclination leads. Absorb every atom of knowledge on that particular subject that comes within reach. The mind will eagerly do so, and you are ready to advance from that

point of supposed perfection where others have left off. A superficial knowledge of a hundred different things is a poor substitute for wisdom in a single sphere, as wisdom is the power of applying knowledge, the ability to put into practice what we have learned with prudence and discretion.

To carry out improvements it is just this mastery of thought and action that we want to gain before all else; no matter by what particular road we gain it, there is no subject that will not yield to its onslaught. It is the master key that will open many doors, and more precious than all the academic distinctions that any man can win.

For this reason science is truth, and great truths all start from the same basis and are founded on the same laws, and the methods of thought applied in one case are equally applicable in others. And that is why all true thinkers and men of action who possess wisdom have views in common, and are able to approach a difficult problem in such a way that it is most easily solved. They seize the essentials, and half the battle is won.

There are no difficulties for those who have gained wisdom: it is only the ignorant who create them. There is no weight of responsibility on the experienced, as they know how to adjust the heaviest load.

Intellectual attainments are often mistaken for wisdom. An engineer may be highly educated in every science, and the recipient of degrees and honours, but the power of vivid reflection or preconception from the analysis of detail and synthetic thought is the only basis of convincing logic and accurate foresight which enables us to utilise precedent and predict the consequences of our deductions. Banish from the mind all thought of in-

spired wisdom. There is no such thing. Some minds will work faster than others, and some subjects are less laborious than others, but the more laborious the subject the greater the measure of the reward. As truth is to false conception, so is wisdom to folly, and folly is the putting into practice of superficial attainments.

INDEX

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